Public Workshop (10/1-2/12)
Bay-Delta Workshop 2
Deadline: 9/14/12 by 12 noon

Bay-Delta Fisheries Resources: Pelagic Organisms

September 14, 2012

Submitted by: State Water Contractors, Inc.
San Luis & Delta-Mendota Water Authority

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Acronyms

BDCP	Bay Delta Conservation Plan
BiOp	biological opinion
cfs	cubic foot/feet per second
CVP	Central Valley Project
CDFG	California Department of Fish and Game
DIN:TP	ratio of dissolved inorganic nitrogen to total phosphorus
DWR	California Department of Water Resources
mg L^{-1}	milligram(s) per liter
NMFS	National Marine Fisheries Service
N:P	ratio of nitrogen to phosphorus
IEP	Interagency Ecological Program
POD	pelagic organism decline
SWP	State Water Project
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Executive Summary

The State Water Contractors and the San Luis & Delta-Mendota Water Authority (Public Water Agencies or PWAs) have conducted a technical assessment of the status and trends of eight fishes of concern in the Sacramento-San Joaquin Delta (Delta or estuary). In the ongoing workshops, the State Water Resources Control Board (State Water Board) has and will continue to receive information regarding the scientific and technical basis for potential changes to the 2006 Water Quality Control Plan for the Bay-Delta. This presentation has been prepared to help inform the second of those workshops on Bay-Delta Fishery Resources. This document addresses fish species other than salmonids, which are described in a companion submission.

These workshops provide an opportunity for the State Water Board to consider the wealth of scientific information that has been developed since it completed the review of the 2006 Bay-Delta Plan and since it released the 2010 Flow Criteria Report.

This submittal assesses the available scientific information on the multiple stressors affecting the Bay-Delta ecosystem and population-level effects on key fish species. An assessment of available scientific information reveals a high degree of uncertainty as to whether Delta through flows, particularly in the form of reservoir releases and export curtailments, affect the abundance of two key fish species, longfin smelt and delta smelt. Conversely, it is fairly well accepted that changes in food resources, in terms of quality and quantity, have likely impacted delta and longfin smelt abundances, and the best available information indicates that these changes have been caused by changes in nutrient loadings. Increasing water temperatures, changes in turbidity, and predation have also likely affected the abundance of the two smelt species. While these stressors are not controllable with reservoir releases or export curtailments, there are other actions that could be taken, including physical habitat restoration and pollution control.

Longfin Smelt

A brief summary of factors the State Water Board should consider when evaluating the need for Delta through flows for longfin smelt include:

- Their abundance index decline (based on the FMWT) is closely tied to food web changes. Invasion and establishment of the Amur River clam, *Potamocorbula amurensis*, and increases in the concentration of ammonium and changes in the ratios of key nutrients are the primary cause of detrimental changes to the food web in the upper estuary.

- There are a number of factors besides the Amur River clam abundances and nutrients that have statistically significant relationships with longfin smelt abundance. They include winter-spring outflow, water clarity, and tributary flows. Water clarity and tributary flows, and other factors, correlate as well or better than winter-spring outflow.

- The longfin smelt's full geographic range in the estuary should be considered. The Bay Study demonstrates that longfin smelt are found in significant numbers far downstream of the low-salinity zone in San Pablo, Central, and South bays in the winter and spring. The Fall Midwater Trawl does not sample longfin smelt's full geographic range, although it does cover the region where most longfin smelt are found in the fall. Catch data from this survey do not well represent longfin smelt that are in deeper waters and the survey area is getting deeper.

- While some longfin smelt are entrained and salvaged by water project operations, they are found infrequently and at very small percentages of the total population in the Delta in areas where the threat of entrainment may be high.

Delta smelt

A brief summary of factors the State Water Board should consider when evaluating the need for Delta through flows for delta smelt include:

- Four life cycle or multi-variable analyses of delta smelt abundance and potential stressors have recently been published (MacNally et al. 2010; Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012). These latter two studies show food resource availability to be a significant driver of delta smelt abundance. Thomson et al. (2010) found weak effects of water clarity and winter exports on delta smelt. MacNally et al. (2010) identified weak effects of predator abundance (largemouth bass) and stronger effects of warmer summer temperatures and duration of water temperatures suitable for spawning. Maunder and Deriso (2011) found that water temperature, prey density, and predators explained the recent decline in delta smelt abundance. And, Miller et al. (2012) found that prey density strongly predicted delta smelt abundance, while water temperature and predators were weakly associated with abundance. None of these models indicate that X2 position in the fall months affects delta smelt abundance.

- Delta smelt do not have a statistically significant relationship between species abundance and low salinity zone volume or winter-spring, summer, or fall outflow.

- Feyrer et al. (2011) proposed a statistically significant relationship between species abundance and an index of habitat quality in the fall. Because the equation contains an induced correlation, the index of habitat quality cannot be relied upon as a predictor of abundance for delta smelt. Initial analyses suggest the relationship between abundance and the habitat index is not significant. Stated differently, because the index of habitat quality is also a measure of abundance, the relationship provides no support for the importance of the habitat quality index. Irrespective of whether the habitat index equation has a statistically significant relationship with abundance, the fall X2 conceptual model has several deficiencies:
    - Data analysis did not include Cache Slough abundance data;

- Studies ultimately focused on a single variable;
- Four life cycle or multi-variable models independently reached the same conclusion: the position of X2 in the fall months has no statistically significant effect on species abundance;
- Suisun Bay is not currently as productive as it once was;
- It is unclear that delta smelt are distributed in relation to the low-salinity zone;
- A complete analysis establishing that the position of X2 can serve as a surrogate for delta smelt habitat needs to be conducted;
- Based on the high flows in 2011, the low Summer Townet Survey results for 2012 would not have been predicted by the fall X2 conceptual model;
- X2 position has not been trending upstream in the fall.

Other Pelagic Organisms

A brief summary of factors the State Water Board should consider when evaluating the need for Delta through flows for other pelagic species include:

- Green sturgeon: There is currently little or no scientific basis that any specific action, such as further modifications of water project operations, will produce negligible, limited, or substantial benefits. Due to a fundamental lack of information on the status of green sturgeon and the factors that limit its numbers, additional research is an essential prerequisite to the identification of additional actions.
- Splittail: No flow-related actions are supported by the scientific literature. The literature supports actions intended to increase the availability of floodplain rearing and spawning habitat for splittail and other fishes, including physical modifications to the Fremont Weir and Yolo Bypass to manage the timing, frequency, and duration of inundation of the Yolo Bypass with gravity flow from the Sacrament River, and to improve upstream fish passage past barriers that include Fremont and Lisbon weirs.
- Starry flounder: Based on the Bay Study Otter Trawl data from the past three decades, starry flounder is not experiencing a decline in abundance in the San Francisco estuary. There is no scientific justification for the SWRCB to take any further actions to maintain the abundance of the fish.
- American shad: American shad is a bay fish that spawns upstream in larger rivers; it is not an estuarine fish. Its weak relationship with the location of X2 in the Delta is likely an artifact of physical circumstances that co-vary with inter-year variation in Delta through flows. Similar to Chinook salmon, the use of the Delta by American

shad is primarily a just-passing-through phenomenon on directional downstream migration to salt waters. The scientific literature does not support additional flow-based action.

- Northern anchovy: The central stock of northern anchovy is not experiencing a decline.

- Striped bass: In spite of the effects of density dependence during their young juvenile stage, sufficient numbers of age-0 fish appear to be recruiting into the adult population. Likewise, recreational catch, the California Department of Fish and Game's (CDFG) designated beneficial use for striped bass, has not declined.

- California bay shrimp: Based on the Bay Study Otter Trawl data, California bay shrimp is not experiencing a decline. There is no reason to believe that further actions are needed to maintain its abundance.

1.0 Longfin Smelt

1.1 Introduction and Summary

A brief summary of factors the State Water Board should consider when evaluating the need for Delta through flows for longfin smelt include:

- Their abundance index decline (based on the FMWT) is closely tied to food web changes. Invasion and establishment of the Amur River clam, increases in the concentration of ammonium, and changes in the ratios of key nutrients are the primary cause of detrimental changes to the food web in the upper estuary.

- There are a number of factors besides the Amur River clam abundances and nutrients that have statistically significant relationships with longfin smelt abundance. They include winter-spring outflow, water clarity, and tributary flows. Water clarity and tributary flows, and other factors, correlate as well or better than winter-spring outflow.

- The longfin smelt's full geographic range in the estuary should be considered. The Bay Study demonstrates that longfin smelt are found in significant numbers far downstream of the low-salinity zone in San Pablo, Central, and South bays in the winter and spring. The Fall Midwater Trawl does not sample longfin smelt's full geographic range, although it does cover the region where most longfin smelt are found in the fall. Catch data from this survey do not well represent longfin smelt that are in deeper waters and the survey area is getting deeper.

- While some longfin smelt are entrained and salvaged by water project operations, they are found infrequently and at very small percentages of the total population in areas of the Delta where the threat of entrainment may be high.

1.2 Life history

The longfin smelt, *Spirinchus thaleichthys*, is a small (90–110 mm standard length at maturity) fish that usually has a 2-year life cycle (Moyle 2002). Historically, populations of longfin smelt in California have been present in the San Francisco estuary, Humboldt Bay, the Eel River estuary, and the Klamath River estuary (Moyle 2002). In the Bay-Delta, it is an anadromous species that spends its life in salt water except for spawning, when it seeks out lower salinity water. It is frequently referred to as a pelagic fish (that is, it lives in open waters), but it is encountered in shallow water circumstances and spawns along shorelines where fresher water meets the estuary (see, e.g., Sommer et al. 2007; Baxter et al. 2010). An examination of the available survey data suggests that a significant fraction of age-2 longfin smelt reside near the bottom (Figure 1). Age-0 and age-1 longfin smelt are almost always found at greater densities deeper in the water-column (Rosenfield and Baxter 2007; Rosenfield 2010).

According to some monitoring surveys, the longfin smelt is among the native species in the San Francisco estuary that have declined dramatically over the past decade and a half (see, e.g., Baxter 1999; Moyle 2002), with a recent rapid collapse coincident with the POD (Baxter et al. 2010). Despite this decline, they have been, and may continue to be, among the most abundant resident pelagic or demersal fish species in the estuary (Dege and Brown 2004; Sommer et al. 2007).

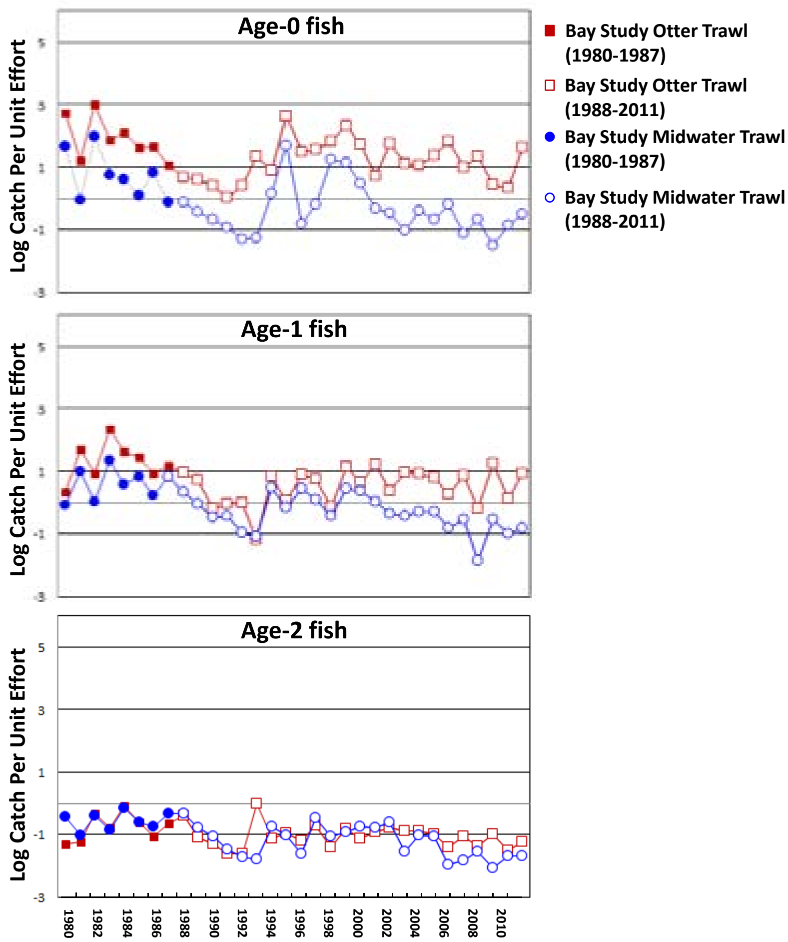

Figure 1. Bay Study Otter Trawl (boxes) and Midwater Trawl (circles) catch per unit effort. Age-0 and age-1 fish catch is greater in the Otter Trawl, which samples near the bottom, than the Midwater Trawl, indicating that many fish are more demersal than pelagic. Age-2 fish are more pelagic. Otter Trawl CPUE converted to the same units as the Midwater Trawl. Data from the California Department of Fish and Game's Bay Study.

As adults mature and prepare to spawn, most often from December through February, they make generally short-distance, brief spawning runs into fresher water where spawning takes place over a sand substrate (Baxter et al. 2009). Hobbs et al. (2010) examined otoliths and isotopic signatures and determined that the salinity preference of larval longfin smelt is broad (from 0-15 ppt), with frequent occurrence in fresher water salinities (~1-3 ppt) and in brackish waters (>5 ppt). Baxter et al. (2010) reports that "nursery habitats" cover a wide salinity range from 0.1-18 ppt.

Moyle (2002) reported that spawning by longfin smelt in the Delta occurs below Medford Island in the San Joaquin River and below Rio Vista on the Sacramento River. The western extent of spawning habitat in the Delta was previously thought to be in upper Suisun Bay around Pittsburg and in Montezuma Slough in Suisun Marsh (Moyle 2002); however, the 20-mm Survey has found large numbers of larval longfin smelt in the Napa River. The conclusions of Moyle (2002) are contradicted by more recent published material. As presented by Leidy (2007) and Rosenfield (2010), other watercourses tributary to San Pablo Bay (e.g., the Petaluma River and Sonoma Creek) and South Bay (e.g., Coyote Creek) may also provide spawning habitat (there are currently no regular fish monitoring programs on those tributary streams), suggesting they are not exclusively dependent on the Suisun Bay region or the low-salinity zone for rearing. The upper end of the spawning habitat in the Delta is in the region of the confluence of the Sacramento and San Joaquin rivers, although the 20-mm Survey records small numbers of longfin smelt as far upstream on the Sacramento River as the Cache Slough region and east into the central estuary; however, these represent a very small percentage of their distribution (e.g., Baxter et al. 2009 characterizes upstream spawning as sporadic and rare). Larvae are found in salinities up to 15 ppt (Hobbs et al. 2010) and juveniles inhabit most of the estuary seaward of about 2 psu (Kimmerer 2002).

1.3 Abundance and Distribution of Longfin Smelt

Rosenfield and Baxter (2007) and Baxter et al. (2009) document that the range of longfin smelt extends into San Francisco Bay. The available data show the primary geographic range of the San Francisco estuary population of longfin smelt extends from the lower Sacramento River confluence downstream through Suisun, San Pablo, and Central bays, and even in South Bay and the near-ocean. Small fractions of the population can be found as far upstream as the American River, the lower San Joaquin River, and various other interior portions of the Delta, Suisun Marsh, and Cache Slough (Figure 2). In every life stage and in every year, most of the population(s) is located in north San Francisco, San Pablo, and Suisun bays. Suisun and San Pablo bays show consistently more frequent longfin smelt occurrences compared with other regions, suggesting those waters serve as potential nursery areas (Figure 3A, 3B, 3C). In contrast, the Delta surveys have shown irregular and small occurrences, suggesting habitats upstream of Suisun Bay may be of lesser quality, or are only utilized under certain circumstances.

The data reflected in Figures 2, 3A, 3B, and 3C suggest that longfin smelt are not tightly associated with a particular salinity or the estuary's low-salinity zone, which is consistent with Kimmerer (2004) and Baxter et al. (2010).

Baxter et al. (2010) reported on a general shift in where longfin smelt are captured in the water column. The ratio of catch in the water column to catch at the bottom declined sharply during the POD years and has remained low, suggesting a shift in habitat use toward the bottom. Through the entire period of record, summer-fall longfin smelt (mostly age-0) catches in the Bay Study Midwater Trawl generally exceeded those in the Otter Trawl in Suisun Bay and the west Delta, whereas from San Pablo Bay downstream the reverse was true. During the POD years, coincident with the sharp drop in the Bay Study Midwater to Otter Trawl catch ratio, relative Otter Trawl catches by embayment shifted downstream and the greatest proportion occurred in Central Bay. Thus, both historical and recent downstream shifts in habitat use seem to have occurred, in addition to the recent shift toward the bottom indicated by the Bay Study Midwater:Otter Trawl ratio decline. These shifts downstream and toward the bottom further suggest that the pelagic feeding environment of the upper estuary has declined and that the longfin smelt response occurred in stages. Also, such shifts undoubtedly affected longfin smelt abundance as indexed by midwater trawls (FMWT and Bay Study Midwater Trawl) and contributed in part to the declines observed in their respective abundance indices. All of this suggests that there is some uncertainty in the results of the trawl data.

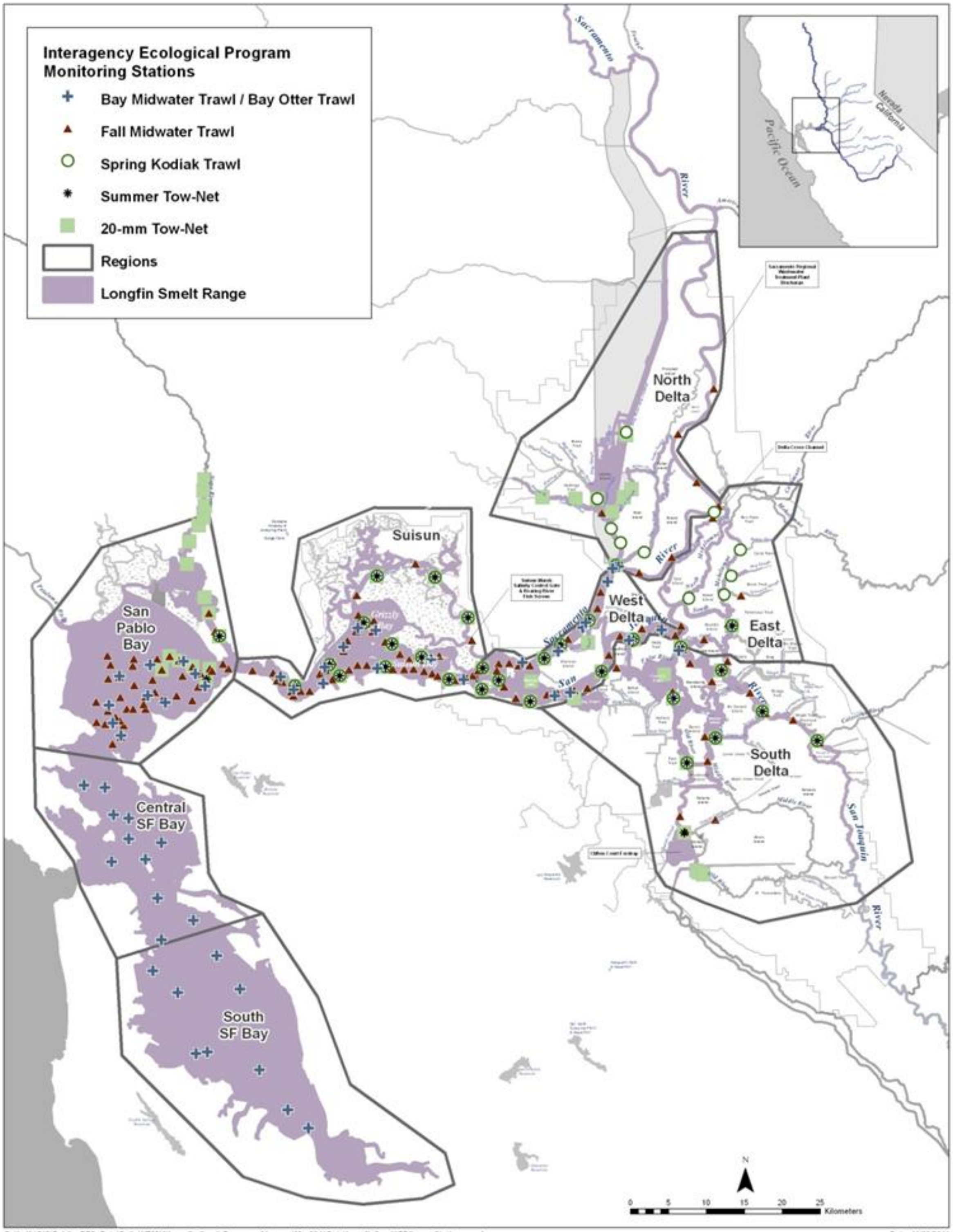

Figure 2. Extent of Interagency Ecological Program monitoring stations. The Fall Midwater Trawl does not extend into Central and South Bays while the Bay Study trawls do. The Bay Study trawls demonstrate that longfin smelt's known range in the estuary extends into these bays. From Gray et al. (in prep).

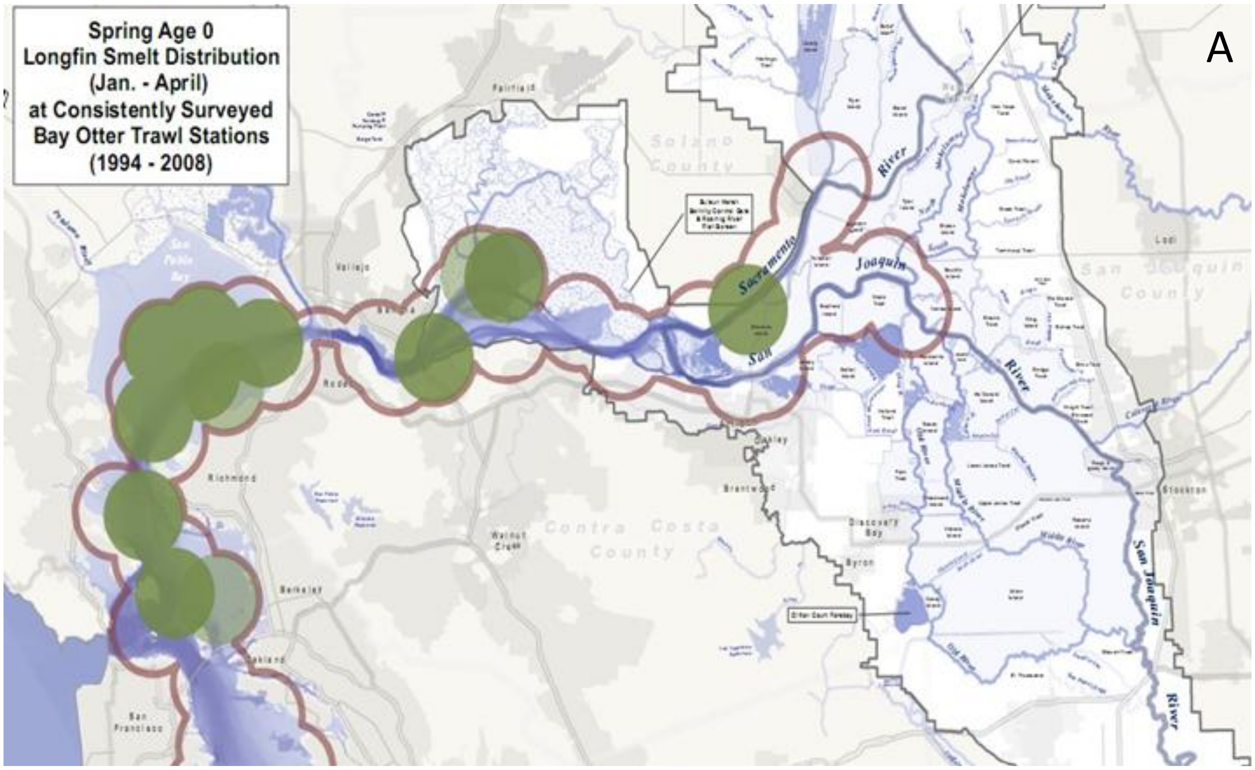

Figure 3A. Spring distribution of longfin smelt in the Bay-Delta system based on catch per unit effort. (A) Age-0 fish. Note, the dark shaded circles represent 90% of the effort adjusted catch (major catch) and the light circles indicates the <9% effort adjusted catch (minor catch). Longfin smelt are found far below the low-salinity zone, especially in San Pablo Bay. From Gray et al. (in prep).

Schoellhamer (2011) notes that the estuary overall is in an erosion state, with its main channels deepening. Such changes in the Delta's bathymetry could further affect the monitoring catch of longfin smelt. The midwater trawls (Bay Study and FMWT) sample to a depth of 10-12 m because of gear limitations. Many of the estuary's main channels now exceed this depth (see Bay Study and FMWT data at http://www.dfg.ca.gov/delta/). Approximately one-third of the Bay Study stations now exceed 12 m in depth. Thus, at many stations the midwater trawls are no longer sampling the deepest stratum of the water, even as longfin smelt catch has been shifting towards the bottom.

1.4 Environmental Factors Affecting Longfin Smelt

1.4.1 Food Resources

Food resources utilized by fishes of concern have declined in the low-salinity zone and upstream on the Sacramento River (Jassby et al. 2002; Kimmerer 2004). Nixon (1988) reports a strong relationship between production at the base of the food web (primary production) and production of fish (fishery yield), providing an explanation for the low fishery production in the Bay-Delta estuary. USFWS (2012) links changes in primary production caused in part by the invasion and establishment of the Amur River clam to longfin smelt population dynamics. Glibert et al. (2011) links changes in primary production to unbalanced nutrient ratios, a change that likely created conditions supportive of the Amur River clam's invasion. While other factors may also be at work, the

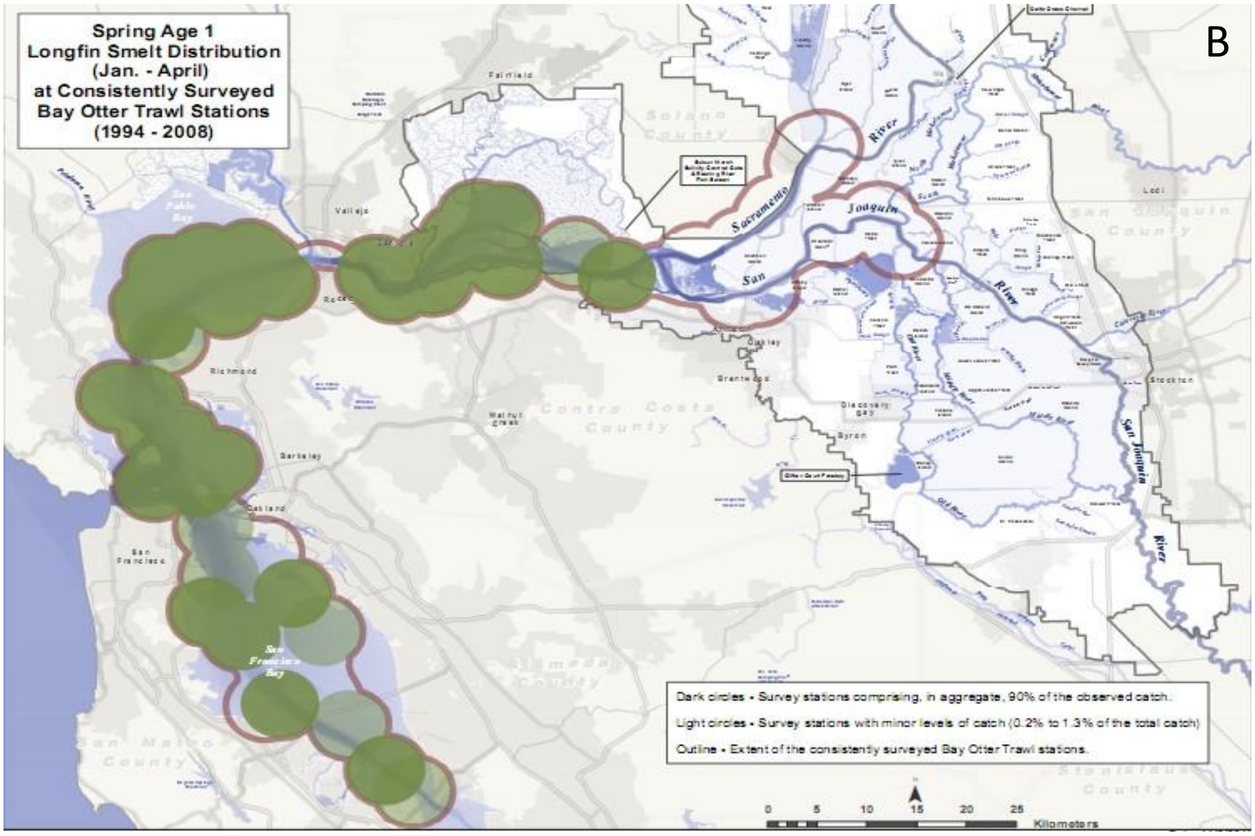

Figure 3B. Spring distribution of age-1 longfin smelt in the Bay-Delta system based on catch per unit effort. Note: the dark shaded circles represent 90% of the effort adjusted catch (major catch) and the light circles indicates the <9% effort adjusted catch (minor catch). Age-1 longfin smelt are found throughout San Francisco Bay and west of the low-salinity zone. From Gray et al. (in prep).

hypothesis that changes in primary production are a strong driver of longfin smelt declines is plausible.

Juvenile longfin smelt feed primarily on calanoid copepods, especially *Eurytemora affinis*, whereas older juveniles and adults feed principally on opossum shrimpand *Acanthomysis* spp. shrimp, when available (Hobbs et al. 2006; Slater 2008; Rosenfield 2010). *E. affinis* is important to age-0 longfin smelt in the spring. In summer and early fall, larger longfin smelt switch to *N. mercedis* (Slater 2008). In later fall, amphipods become regionally more important. Opossum shrimp has declined substantially in the estuary since the early 1970s (Orsi and Mecum 1996); when opossum shrimp are less abundant, adult longfin smelt return to feeding primarily on copepods and amphipods (Feyrer et al. 2003; Hobbs et al. 2006; USFWS 2012). It is widely accepted that food resources preferred by native fishes have suffered a major decline in the Delta (Kimmerer 2002; Moyle 2002; Rosenfield and Baxter 2007), being replaced by smaller, less nutritious taxa (Lehman 2000; Lehman et al. 2005; Lehman et al. 2010; Jassby et al. 2002; Sommer et al. 2007; Glibert et al. 2011; Winder and Jassby 2010).

Invasion of the estuary by the Amur River clam, *P. amurensis,* led to a sharp decline in the abundance of *E. affinis*, *N. mercedis*, and other mysids in the Suisun Bay region (Orsi and

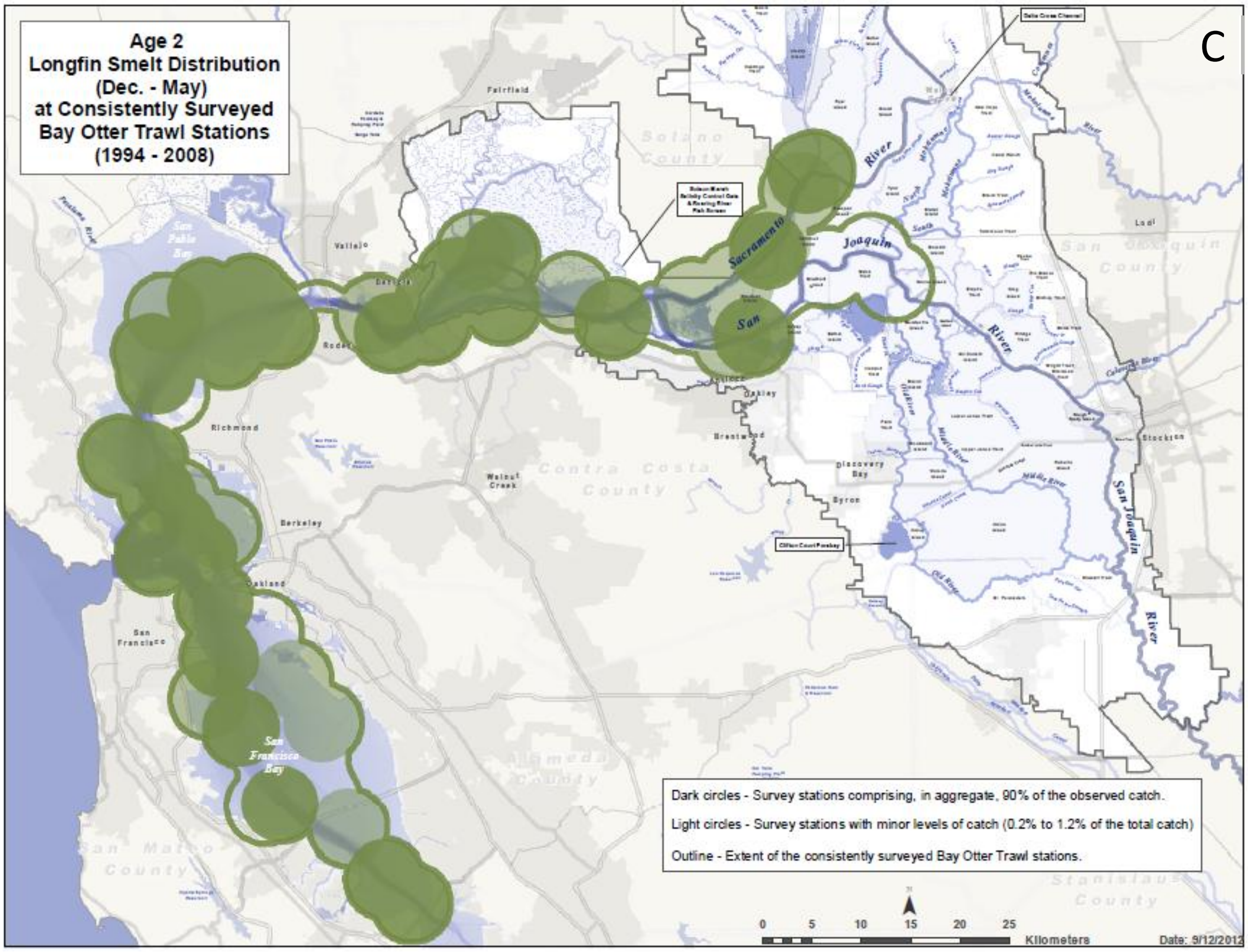

Figure 3C. Spring distribution of age-2 longfin smelt in the Bay-Delta system based on catch per unit effort. Note: the dark shaded circles represent 90% of the effort adjusted catch (major catch) and the light circles indicates the <9% effort adjusted catch (minor catch). Adult longfin smelt are found throughout the estuary. From Gray et al. (in prep).

Mecum 1996). After examining a number of potential causes of the opossum shrimp decline, Orsi and Mecum concluded that food limitation caused by grazing of the Amur River clam is the most probable cause. A factor leading to their conclusion is that, after 1984, the percent of large mysids (>11 mm) declined and was very low from 1988 to 1993. Orsi and Mecum concluded that so long as *P. amurensis* remains abundant in Suisun Bay, the abundance of *N. mercedis* is likely to also remain low. Additionally, the introduction and population increase of two Asian mysids in 1992 may compete with *N. mercedis* for resources (Orsi and Mecum 1996). According to Glibert et al. (2011), changes in nutrient forms and ratios may have played a role in the successful invasion by and establishment of the Amur River clam.

In addition to the food limiting effects of the Amur River clam, *E. affinis* and the opossum shrimp also suffered further declines because of unbalanced nutrient ratios that favor smaller, less nutritious taxa (Lehman 2000; Lehman et al. 2005; Lehman et al. 2010; Jassby et al. 2002; Sommer et al. 2007; Winder and Jassby 2010; Glibert et al. 2011; Glibert 2012).

A manifestation of the imbalance in the nitrogen:phosphorus ratio may have created conditions favorable for invasion by the Amur River clam (Glibert et al. 2011). A detailed discussion of the current condition of the estuary's food web is found in the PWA's submittal, *Ecosystem Changes to the Bay-Delta Estuary: A Technical Assessment of Available Scientific Information*, dated 16 August 2012.

A potential response by fishes to reduced food supplies in a region is to move to more favorable areas without such limitations, if possible. A change in distribution from areas of low food availability to more productive areas may have occurred, as Baxter et al. (2010) notes that shifts in distribution away from habitats sampled by the Fall Midwater Trawl may explain some of the decline in longfin smelt in the FMWT abundance index, just as it has for striped bass (Sommer et al. 2011) and northern anchovy (Kimmerer 2006).

Reduced abundance is not observed in the Bay Study Otter Trawl (Baxter et al. 2010), which samples down through San Pablo, Central, and South bays (see Figure 1); these regions have not experienced as severe a drop in chlorophyll-*a* as seen in Suisun Bay and the Delta (Kimmerer 2004).

1.4.2 Entrainment

Grimaldo et al. (2009) stated: "*There is considerable concern about the number of fish entrained at the export facilities. Unlike the X2-fish relationships, there is no direct evidence that entrainment affects population-level responses of fish.*" Likewise, Baxter et al. (2010) acknowledged that the effects of entrainment on the longfin smelt population was unknown. Except for 2002, when an unusual number of longfin smelt were salvaged, entrainment by the water projects has been very low. USFWS (2012) reported the total number of spawning age longfin smelt salvaged at both pumps between 1993 and 2007 was 1,133 (an average of 87 fish per year). Baxter et al. 2009 characterizes upstream spawning, which may increase the likelihood that larval longfin smelt could be entrained, as sporadic and rare.

Rosenfield (2010) hypothesized that the water projects may entrain significant numbers of larval longfin smelt in low outflow years and immediately after the spawning period.[1] Using particle tracking models and distributional assumptions, Baxter et al. (2009) estimated that larval entrainment at the water projects might be 2-10% of the total larval population. Table 2 of Baxter et al. (2009) indicates that entrainment of larval longfin smelt can reach the tens of thousands, and may have reached over a million fish in 2002; however, Table 2 of Baxter et al. (2009) is based at least partially on prescreen losses of juvenile Chinook salmon, delta smelt, striped bass, and steelhead trout (see Baxter et al. 2009, Appendix B). As these species have not been verified as appropriate surrogates for juvenile or adult longfin smelt for the purpose of estimating entrainment, Baxter et al.'s (2009) estimates are uncertain. And, based on the 20-mm Survey, which does not survey the entire range of longfin smelt, only small numbers of larval-juvenile longfin smelt are found in the sub-region of the Delta in which the pumps are located, indicating that entrainment of larvae is

[1] Fish less than 20-mm are not efficiently captured by the salvage facilities and are not counted in salvage surveys.

expected to be low. As previously mentioned and as demonstrated by Figures 3A-3C, in every life stage and in every year the bulk of the longfin smelt population is located in Central, San Pablo and Suisun bays (Figure 4).

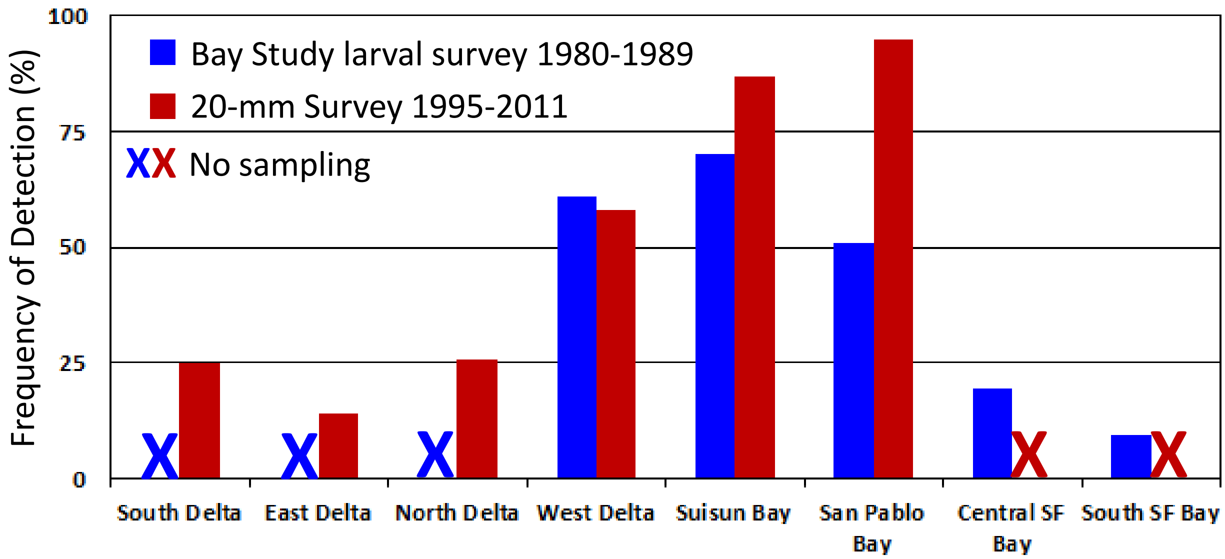

Figure 4. Percent frequency of detection of age-0 longfin smelt by region. “X” indicates no sampling and “0” indicates sampling but no longfin smelt observed. Data were from BMWT = Bay Study Midwater Trawl; BOT = Bay Study Otter Trawl; Kodiak = Spring Kodiak Trawl.

Baxter et al. (2009) also used particle tracking model runs to estimate the potential for entrainment of larval longfin smelt. Seven particle injection points were chosen, most of which were in the interior Delta and up to the Cache Slough region, areas which are outside the typical distribution of longfin smelt. Each of the insertion points introduced 5,000 particles, even though Baxter et al. (2009) characterizes upstream spawning as sporadic and rare. This casts further uncertainty on Baxter et al.’s (2009) conclusions on longfin smelt entrainment.

The importance of entrainment by the CVP and SWP pumping plants us further questioned by the data which show that far more longfin smelt are caught as bycatch – a form of entrainment – in small bay shrimp trawl fishery and bait fishing (anchovies and sardines) operations in South San Francisco Bay, San Pablo Bay, and Carquinez Strait (CDFG 2009). The California Department of Fish and Game estimated the total longfin smelt bycatch from shrimping in 1989 and 1990 at 15,539 fish, and in 2004 at 18,815-30,574 fish. Even though the bay shrimp trawl industry has declined since 2004, it continues to entrain longfin smelt at levels greater than those attributed to the water projects (USFWS (2012).

1.5 Reasons for Caution Regarding Flow Relationships

Numerous sources have described the positive correlation between winter-spring estuary outflow and longfin smelt abundance (see, e.g., Stevens and Miller 1983; Jassby et al. 1995; Kimmerer 2002, 2004; Kimmerer et al. 2009). However, the biological mechanism(s) of the spring X2:longfin smelt abundance relationship remains unknown (Kimmerer et al. 2009; Baxter et al. 2010), even though considerable research efforts have been undertaken since

1995 to better understand the causal mechanisms underlying the relationship (see, e.g., Sommer et al. 2007; MacNally et al. 2010; Rosenfield 2010; Thomson et al. 2010). Without an understanding of the causal mechanisms, significant uncertainty exists with any management action that is based on outflow:abundance relationships.

The Jassby et al. (1995) study, which was the basis for the X2 standard adopted by the SWRCB in D-1641, cautioned: "*What are the causal mechanisms underlying these [salinity:organism] relationships? A variety of potential mechanisms deserves detailed consideration that is beyond the scope of this study…*" and "*In certain cases, variables correlated with X, or net Delta outflow are thought to be important causal factors. These correlations may not persist into the future if the estuary is managed in a different fashion, and the utility of X, as a predictor may no longer hold.*" Kimmerer (2002), which reevaluated the Jassby et al. (1995) X2:organism relationships and attempted to identify mechanisms of effect, acknowledged: *"The current state of knowledge about flow effects does not provide adequate support to decision making. The salinity standard is a crude tool that could possibly be made more effective. Major changes in configuration of the Delta or regional climate could result in unanticipated changes in flow response of the estuarine ecosystem. Reductions in export flow are inadequately supported by evidence, evidence, and there is little understanding of population-level effects of entrainment in export pumping facilities. The effectiveness of export reductions using environmental water has not been put in a population-level context or compared with alternative actions in the watersheds. All of these problems are shortfalls of knowledge that can be addressed through a program of research coupled with experimental manipulation of some aspects of freshwater flow.*" Kimmerer et al. (2009), which again examined X2:habitat relationships for several estuarine organisms, concluded that longfin smelt are not among the fish species whose habitat area were shown to benefit from increased seasonal flows through the Delta.

Not only does the scientific literature question the reliance on flow:abundance relationships, but consideration of the relationship of other factors and abundance raises additional uncertainty. While longfin smelt abundance based on the FMWT is correlated with winter-spring X2, it is also strongly and directly correlated with ammonium (Glibert 2010; Glibert et al. 2011), nutrients (Glibert et al. 2011), food resources (especially mysid shrimp; Chigbu et al. 1998), Secchi depth, and winter-spring Napa River flows. (See Figure 5.) Importantly, at least some of these other relationships have direct causal mechanisms. That is, the scientific literature explains the direct impacts of food resources (caused by ammonium and nutrients) and/or the effect of nutrient ratios on primary productivity and speciation.

Another area of uncertainty regarding the statistical relationship between outflow and abundance is due to the specific survey data used. Jassby et al. (1995) examined the relationship between the location of the X2 isohaline in the winter:spring and the abundance of longfin smelt based on the Fall Midwater Trawl. As previously discussed, the

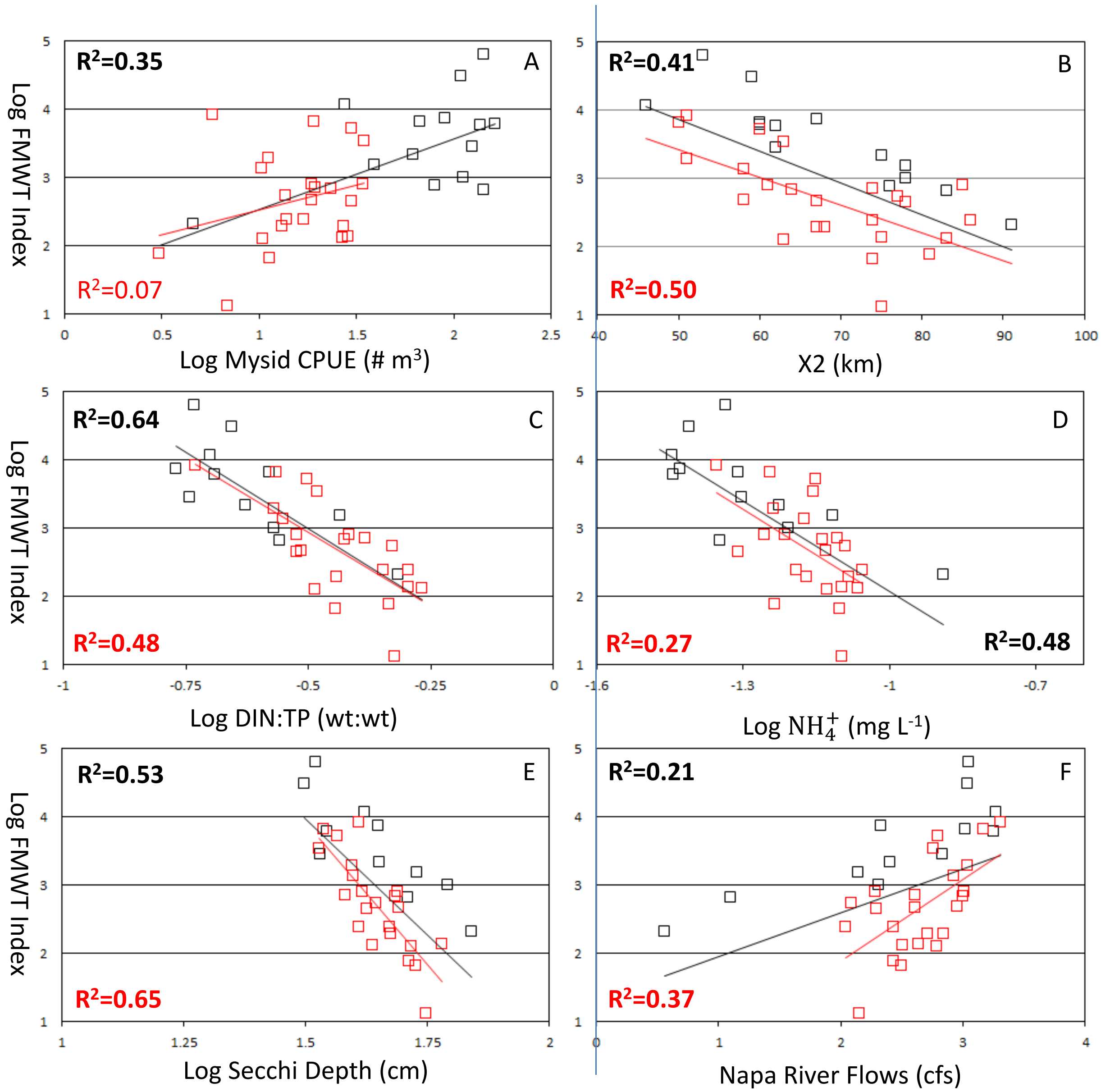

Figure 5. Relationships between various factors and longfin smelt FMWT Index. (A) Mysid CPUE (#/m^3); (B) X2 (km); (C) DIN:TP (wt:wt); (D) NH_4^+ (mg L^{-1}); (E) Secchi Depth (cm); (F) Average Napa River flows Jan-Mar (cfs). Except for X2, all values are log values. Black boxes 1975-1988; red boxes 1988-2011 except for (C), (D) and (E) which are 1988-2010. Black lines 1975-2011 except for (C), (D) and (E) which are 1988-2010; red lines 1988-2011 except for (C), (D) and (E) which are 1988-2010. Bold R^2 values are significant at $p \leq 0.05$.

Fall Midwater Trawl misses much of the range of longfin smelt (see Figure 2, Figures 3A-3C).

Another area of caution relates to differences in efficiencies between the fish monitoring surveys. The Fall Midwater Trawl is conducted from September-December using a large net towed mid-channel and obliquely from the bottom to the surface. It primarily samples age-0 longfin smelt. Gear limitations prevent the nets from sampling deeper than approximately 10-12 m; many monitoring stations now exceed 10-12 m in depth. The Bay Study Otter Trawl is conducted throughout the year using a net designed to travel along the channel bottom picking up demersal organisms (although there may be some residual sampling of other water depths as the net is lowered and raised to the surface) (see state Department of Fish and Game's website for a description of trawl gear). The Bay Study Otter Trawl and its related Midwater Trawl samples the area covered by the FMWT and also downstream (see Figure 2). The Bay Study is the only one that covers the Central and South Bays, the downstream range of longfin smelt in the estuary.

The differences in the fish monitoring surveys can be illustrated by examining the post-1987 period (Figure 6). Much of the longfin smelt population decline appears to have occurred shortly after 1987 (see, e.g., Jassby et al. 1995; Kimmerer et al. 2009), with only moderate declines since then. The Bay Study Midwater Trawl and FMWT indicate a continued but slower rate of decline since approximately 2000, while the Bay Study Otter Trawl indicates a level or slightly rising trend. In addition, it appears that as Secchi depth decreases (turbidity increases) the Otter Trawl catch increases and the Fall Midwater Trawl decreases. The fact that the Bay Study Midwater Trawl, FMWT, and Otter Trawl present a different picture of historical trends indicates there is still uncertainty regarding longfin smelt's true population status. And, the average depth of the estuary's bays has been increasing over time (Jaffe et al. 1998; Cappiella et al. 1999). The estuary is in an erosion stage, resulting in deepening channels (Schoellhamer 2011). In addition, the efficiency of the midwater trawls may have decreased over time as the channels have eroded.

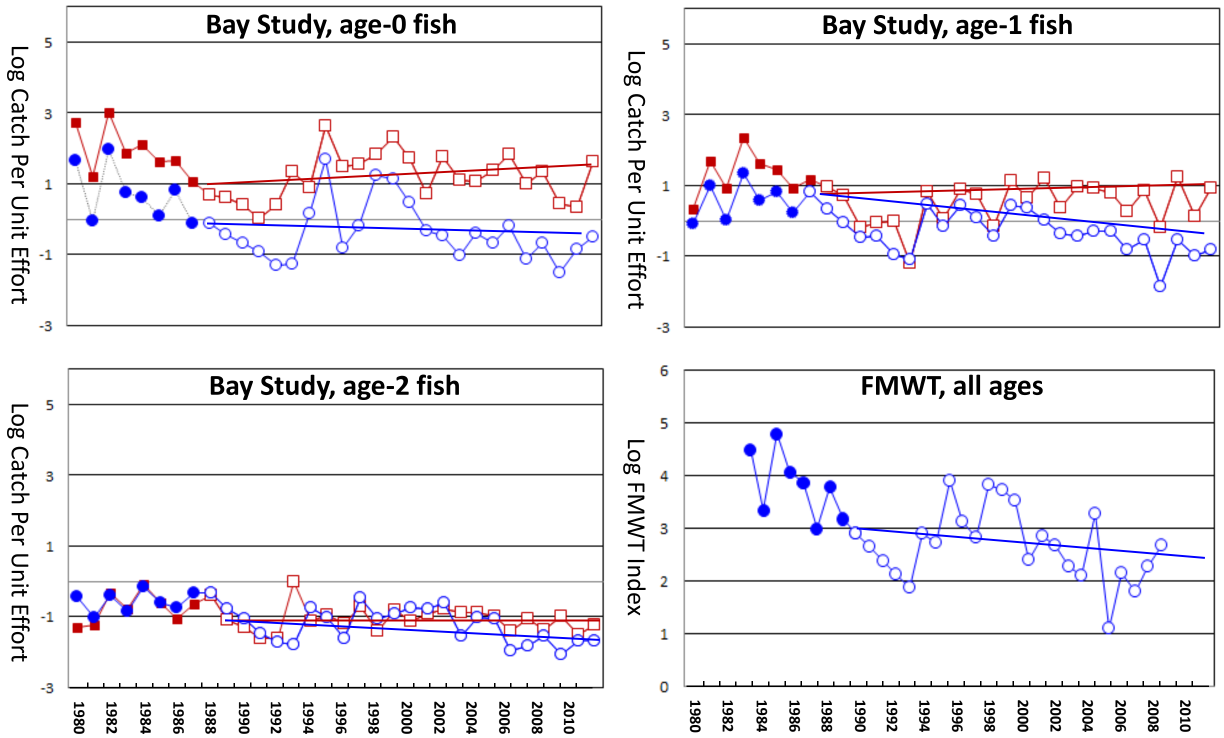

Figure 6. Bay Study trawls catch per unit effort and Fall Midwater Trawl index. Boxes are Bay Study Otter Trawl; circles are Bay Study Midwater Trawl or Fall Midwater Trawl (D). Filled symbols are 1980-1987; open symbols are 1988-2011. Trend lines are for 1988-2011. All midwater trawls show declining trends while the Bay Study Otter Trawl shows flat or slightly increasing trends.

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2.0 Delta Smelt

2.1 Introduction and Summary

A brief summary of factors the State Water Board should consider when evaluating the need for Delta through flows for delta smelt include:

- Four life cycle or multi-variable analyses of delta smelt abundance and potential stressors have recently been published (MacNally et al. 2010; Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012). These latter two studies show food resource availability to be a significant driver of delta smelt abundance. Thomson et al. (2010) found weak effects of water clarity and winter exports on delta smelt. MacNally et al. (2010) identified weak effects of predator abundance (largemouth bass) and stronger effects of warmer summer temperatures and duration of water temperatures suitable for spawning. Maunder and Deriso (2011) found that water temperature, prey density, and predators explained the recent decline in delta smelt abundance. And, Miller et al. (2012) found that prey density strongly predicted delta smelt abundance, while water temperature and predators were weakly associated with abundance. None of these models indicate that X2 position in the fall months affects delta smelt abundance.

- Delta smelt do not have a statistically significant relationship between species abundance and low-salinity zone volume, winter-spring, summer, or fall outflow.

- Feyrer et al. (2011) proposed a statistically significant relationship between species abundance and an index of habitat quality in the fall. Because the equation contains an induced correlation, the index of habitat quality cannot be relied upon as a predictor of delta smelt abundance. Initial analyses suggest the relationship between abundance and the habitat index is not significant. Stated differently, because the index of habitat quality is also a measure of abundance, the relationship provides no support for the importance of the habitat quality index. Irrespective of whether the habitat index equation has a statistically significant relationship with abundance, the fall X2 conceptual model has several deficiencies:

    - Data analysis did not include Cache Slough abundance data;

    - Studies ultimately focused on a single variable;

    - Four life cycle or multi-variable models independently reached the same conclusion: the position of X2 in the fall months has no statistically significant effect on species abundance;

    - Suisun Bay is not currently as productive as it once was;

    - It is unclear that delta smelt are distributed in relation to the low-salinity zone;

- A complete analysis establishing that the position of X2 can serve as a surrogate for delta smelt habitat needs to be conducted;
- Based on the high flows in 2011, the low Summer Townet Survey results for 2012 would not have been predicted by the fall X2 conceptual model;
- X2 position has not been trending upstream in the fall.

2.2 Delta Smelt Biology

The delta smelt, *Hypomesus transpacificus,* is a small, almost transparent, euryhaline fish species with a mostly annual life cycle. Most adults die following spawning in the spring, but a few survive a second year (Moyle et al. 1992; Bennett 2005). Young delta smelt emerge in the late winter or early spring, grow rapidly during summer, and reach adulthood in the fall months (Moyle 2002).

Water temperatures over about 25°C are lethal and can constrain delta smelt habitat, especially during summer and early fall (Swanson et al. 2000). The fish has been found as far west as San Pablo Bay and as far upstream on the Sacramento River as the confluence between the Sacramento and Feather rivers (Merz et al. 2011). In most years, the bulk of the population is distributed from Grizzly Bay to the Cache Slough region (Merz et al. 2011). In recent years, monitoring catch in the Cache Slough region, including the Sacramento Deep Water Ship Channel, has demonstrated that this region is vitally important to the population.

2.3 Delta Smelt Habitat

Habitat for a species is generally defined as a geographic area that supports the physical (abiotic) and biological (biotic) resources upon which a species depends. For analytical purposes and for assessing effects, this approach has not been used by the fishery agencies; rather, the location of X2, or the volume of water in the low-salinity zone, has been used to measure habitat changes. Therefore, instead of considering the full range of habitat features that delta smelt utilize, the fishery agencies have generally only looked at one – X2 position. If a habitat surrogate such as X2 position is to be used, there needs to be an accompanying analysis explaining why that single factor accurately predicts changes in the array of habitat features that define species habitat.

Part of the difficulty in defining habitat for delta smelt is that there is limited research on the habitats that delta smelt prefer, as well as a comprehensive understanding of why smelt are distributed as they are, with a large segment of the population occurring in comparatively fresh water year round. There is also much that still needs to be learned about how delta smelt use their environment at various life stages (e.g., whether delta smelt migrate, their mobility at various life stages, habitat preferences, etc.).

There are a variety of researchers investigating the habitat needs and preferences of delta smelt. This research includes work by Hamilton and Murphy. Their work may provide an operational description of habitat. The Hamilton and Murphy habitat affinity analysis covers multiple life stages of the delta smelt drawn from time-series data from four trawl surveys, and data on environmental attributes taken from throughout the distribution of the fish. Ranges of conditions acceptable to delta smelt for each of seven environmental attributes were identified. Low turbidity and high water temperatures render a large portion of the estuary seasonally unacceptable to delta smelt. Within areas that experience largely acceptable water quality conditions, patterns of delta smelt occurrences indicate that habitat occurs where deep channels adjoin shallow-water circumstances and extensive patches of emergent vegetation. Habitat suitability indices show that favored environmental circumstances vary with life stages, and delta smelt move as they mature to access suitable areas with environmental attributes in acceptable ranges. Areas that exhibit highest geometrically weighted average HSI values for environmental attributes are displayed on maps, and can be viewed as representing potential priority target areas for habitat restoration efforts.

Hamilton and Murphy (in prep) describe habitat for delta smelt as:

> "…areas in the northern and central estuary that are characterized by complex bathymetry, with deep channels close to shallows and shorelines, with little submerged vegetation, but immediately bounded by extensive tidal or freshwater marshlands. Such situations appear to contribute to local production of diatom-rich phytoplankton communities that support calanoid copepods, in particular *Eurytemora* and *Pseudodioptomus*, and some cyclopoid zooplankton, which are frequent in the diets of delta smelt. The fish demonstrates affinities for waters that experience salinity in the range of 200-8000 EC, a water transparency (Secchi depth) less than 50 cm, and temperatures below 22 degrees Celsius, with preferred conditions varying somewhat with life stage. Before spawning, delta smelt initiate a diffuse landward dispersal to fresher-water circumstances, and while little is known about the microhabitat conditions required for successful spawning, preferred substrates may include clean cobble or sandy surfaces to which eggs are adhered. Delta smelt frequently are found in open water situations, but less so during spawning. Where pre-spawning delta smelt must disperse greater distances to spawning areas, intervening areas of the estuary, including some areas with conditions less suitable for delta smelt, are included as habitat."

Sommer and Mejia (in review) largely corroborates the habitat preference findings of Hamilton and Murphy (in prep), although Sommer and Mejia did not perform affinity or similar habitat preference analyses.

While not the definitive work, Hamilton and Murphy (in prep) does provide an initial framework for further study regarding delta smelt habitat preferences. Future habitat restoration projects should consider the design elements proposed by Hamilton and Murphy, thereby testing their habitat models as part of a practical experiment that will assist in defining delta smelt habitat.

2.4 Environmental Factors Affecting Delta Smelt

There are four delta smelt life cycle analyses that have been published, each evaluating the available data with the intention of learning more about the environmental stressors driving delta smelt abundance. Each model was created independently of the others and as a result the approaches and data sets used in each analysis differ. The results of these analyses provide insight into the drivers of delta smelt abundance, particularly where there is substantial agreement between the models. The models generally agree that food resources are important, as well as temperature and predation. Fall X2 position was not identified as a driver of abundance.

2.4.1 Nutrients

Recent analyses have demonstrated inhibitory effects of ammonium on the nitrogen uptake and productivity of phytoplankton (Wilkerson et al. 2006; Dugdale et al. 2007; Brooks et al. 2012; Parker et al. 2012a, 2012b) and the effects of an altered N:P ratio on community structure (Glibert 2010; Glibert et al. 2011; Glibert 2012). Both of these effects occur in the Delta, particularly in Suisun Bay, where previously large springtime blooms of phytoplankton occurred but which are currently rare. Evidence that the Delta suffers from the long-term consequences of changes in nutrient forms and ratios is found in the decline of diatoms and dominance of flagellates and cyanobacteria (Brown 2009; Glibert et al. 2011). Major changes in the estuary's food web have lowered its carrying capacity for higher trophic levels (Kimmerer et al. 2000). Changes in nutrient forms and ratios offer a plausible biological mechanism for trophic changes (Glibert 2010; Glibert et al. 2011). Evidence of glycogen depletion demonstrates that delta smelt in at least some regions of the estuary are food limited (Bennett 2005; Bennett et al. 2008). A decline in average length at age is further evidence for food shortages (Sweetnam 1999; Bennett 2005). Glibert et al. (2011) found a relationship between phosphorus and length at age, suggesting a stoichiometric explanation. (See expanded discussion of nutrients in PWA submittal for ecosystem change and low salinity zone workshop and presentation by Dr. Patricia Glibert.)

2.4.2 Declines in Primary Productivity

Significant changes to the estuary's food web have occurred, particularly when the Amur River clam became abundant after 1987 (Carlton et al. 1990; Alpine and Cloern 1992; Kimmerer et al. 1994; Feyrer et al. 2003; Kimmerer 2006; Feyrer et al. 2007; Greene et al 2011). Kimmerer et al. (1994) reported a 69 percent drop in chlorophyll concentration after the Amur River clam became abundant. Because it consumes diatoms and copepod nauplii, *P. amurensis* has played a role in the restructuring of the plankton community in the estuary (Carlton et al. 1990; Kimmerer et al. 1994). Greene et al. (2011) found that *P. amurensis* also feeds heavily on microzooplankton (e.g., ciliates), which are a food resource for macrozooplankton (e.g., copepods). As a result, the Amur River clam may disrupt the link between these trophic levels (Greene et al. 2011).

The Amur River clam has a wide tolerance for salinity, being found in the full range of bay salinities (<1 to 33‰) (Carlton et al. 1990). The euryhaline Asiatic bivalve *Corbicula* *fluminea* invaded the estuary in the 1940s. On average, it has been more abundant in the central Delta and Suisun Bay regions after wet years, while the Amur River clam has been more abundant, mostly in the Suisun Bay region, in dry years (Peterson and Vayssières 2010). This fact has significant implications to species recovery, since it is likely that changes in salinity simply shifts the dominant benthic bivalve community from one species to another (Peterson and Vayssières 2010).

A second driver of change to the estuary's food web came into play when increasing anthropogenic discharges of nitrogen were coupled with reductions in phosphorus loading in the estuary (Van Nieuwenhuyse 2007; Glibert et al. 2011). Changes in nutrient forms and ratios caused stoichiometric changes in lower trophic levels, away from a diatom-based food web and toward a less efficient bacterial food web (Glibert 2010; Glibert et al. 2011). According to Glibert (2010), the decline in diatoms, which began in 1982, is highly correlated with the increase in ammonium loading. (Delta smelt abundances experienced a step change in 1981-1982 (Kimmerer et al. 2009)). Diatoms prefer – and, under some conditions, physiologically require – nitrate over ammonium, unlike many other algae which preferentially use ammonium over other nitrogen forms. As nitrate became less available relative to ammonium in Suisun Bay, a competitive advantage shifted to phytoplankton taxa that can more efficiently use reduced forms of nitrogen. Among the phytoplankton groups that replaced diatoms in the estuary, cyanobacteria and many flagellates show a preference for chemically reduced forms of nitrogen (Berg et al. 2001; Glibert et al. 2004, 2006; Brown 2009).

Today, the Suisun Bay region is dominated by cyanobacteria and flagellates (Brown 2009). Observed changes in zooplankton composition are consistent with ecological stoichiometric principles, which predict that consumers that successfully sequester the nutrient in lesser supply relative to their needs should dominate and, in so doing, may stabilize at a new stable state (Glibert et al. 2011). Ecological stoichiometry theory predicts that systems that shift from low to high nitrogen-to-phosphorus ratios should sustain shifts from planktivores to piscivores or omnivores (Sterner and Elser 2002). As mentioned previously and in the PWAs' submittal, *Ecosystem Changes to the Bay-Delta Estuary: A Technical Assessment of Available Scientific Information*, dated 16 August 2012, this is clearly what has happened in the Delta. Glibert et al. (2011) reviews several other estuaries where nutrient changes have caused similar effects on estuarine biota.

Combined, the effect on the estuary's food web has been severe – its apparent carrying capacity for multiple desired fish species has been reduced as the effects of an altered food web have cascaded upward to higher trophic levels (Kimmerer et al. 2000). Additional Delta through flows are unlikely to affect abundance of invasive bivalves, which shift their location in the estuary depending on salinity. Glibert (2010) points out that the current strategy of salinity management will likely show little beneficial effect on phytoplankton, zooplankton, or fish.

2.4.3 Predation

Predation may be an important stressor effecting delta smelt abundance. Maunder and Deriso (2011) found that predation was one of the main variables explaining variations in delta smelt abundance, but MacNally et al. (2010) and Miller et al. (2012) described weaker effects of predation. It is known that striped bass prey on delta smelt due to their ubiquitous distribution in the estuary (Nobriga and Feyrer 2007), although it is uncommon in the gut contents of striped bass (Bennett 2005). Inland silversides *Menidia berrylina* are usually collected in areas where delta smelt spawn and may prey on their eggs and larvae (USFWS 1996; Bennett and Moyle 1996; Bennett 2005). Additionally, inland silversides may compete with juvenile and adult delta smelt for resources (Bennett 1996; 2005). Bennett and Moyle (1996) describe a negative relationship between silverside abundance and delta smelt abundance, particularly in dry years. Using qPCR genetic techniques, Cavallo et al. (2011) found DNA from delta smelt in the digestive tracts of 37% of the inland silversides collected during a Spring Kodiak Trawl survey. Further qPCR research confirms that inland silversides are a significant predator on delta smelt (UCD 2012). The chameleon goby *Tridentiger trigonocephalus* and yellowfin goby *Acanthogobius flavimanus* may also prey on delta smelt eggs and larvae and interfere with recovery of the species (USFWS 1996).

Although inland silversides were found to be the most prolific predator on delta smelt, ongoing predation research at U.C. Davis reveals that a greater number of species are now known to prey on delta smelt, including Chinook salmon, Siberian shrimp *Exopalaemon*, perch and sunfish, largemouth bass, Sacramento pikeminnow, and threadfin shad. Predators were caught both in near-shore and open waters (UCD 2012).

2.4.4 Water Temperatures

Water temperature was identified by Maunder and Deriso (2011) as a significant determinant of delta smelt abundance. The results of Maunder and Deriso (2011) suggest water temperatures throughout the estuary are becoming less hospitable for delta smelt. MacNally et al. (2010) found lesser effects of warmer summer temperatures and duration of water temperatures during spawning. Bennett (2005) noted that longer spawning periods in cooler years can produce more cohorts and on average higher numbers of adult delta smelt. In particular, warmer summer water temperatures have made the south Delta, especially the San Joaquin region, inhospitable for delta smelt (Nobriga et al. 2008). Indeed, since 1978, the Summer Townet Survey has experienced near-zero catches of delta smelt in the San Joaquin region (Nobriga et al 2008). Nobriga et al. (2008) found that summer water temperature acted somewhat like a switch, with capture probability decreasing abruptly at about 24^{o}C. Wagner et al. (2011) predict that climate change will increase the number of days above delta smelt's thermal maxima (especially along the Sacramento River) and may influence a shift to earlier spawning; however, as presented in the PWAs' submittal, *Ecosystem Changes to the Bay-Delta Estuary: A Technical Assessment of Available Scientific Information*, dated 16 August 2012, the scientific literature supports a conclusion that reservoir releases do not influence water temperatures in the Delta or downstream.

Water temperatures throughout most of the estuary are governed to a great extent by air temperature (Kimmerer 2004; Jassby 2008; Cloern et al. 2011). Therefore, while climate change models predict that water temperatures will continue to increase, reservoir releases are unable to moderate Delta water temperatures.

2.4.5 Entrainment

While Maunder and Deriso (2011) noted entrainment of adult delta smelt as weakly related to its abundance[2], numerous scientific articles reference the potential deleterious effects of entrainment in water operations facilities on delta smelt (Moyle 2002; Dege and Brown 2004; Bennett 2005; Kimmerer 2008). Kimmerer (2008) is the only article that attempts to quantify these effects. Kimmerer estimated that entrainment losses may be 0-40 percent of the population throughout the winter and spring, but entrainment effects on year-over-year abundance were found to be small and dwarfed by the 50-fold variation in summer-fall survival. Miller (2011) discusses several upward biases in Kimmerer's (2008) analyses for delta smelt. Kimmerer (2011) responded to Miller (2011) and adjusted his estimates down. Grimaldo et al. (2009) acknowledge that there is no evidence of entrainment effects on the population of delta smelt.

In its delta smelt BiOp, FWS undertook an analysis of raw salvage data to justify controls on water project operations to limit reverse flows in Old and Middle Rivers (OMR). There have been criticisms of the FWS' OMR analysis, including a concern with the FWS's failure to normalize the data. The FWS has since addressed this specific concern by normalizing its data in its recent submittal to the State Board for the ecosystem change and low salinity zone workshop. Other analysis, however, have showed that the FWS' OMR approach is not necessarily the best way to management SWP-CVP project operations to avoid large delta smelt entrainment events. More specifically, Deriso (2011) demonstrated that entrainment of spawning adults can be predicted by including three-day turbidity averages into the trigger for OMR flow. Incorporation of the three-day turbidity averages provides an equivalent level of protection at far less water cost than the FWS's analysis. In essence, the largest entrainment effects are avoided, consistent with Kimmerer's (2008) contention that entrainment effects are episodic, and with Grimaldo et al. (2009), which found that delta smelt salvage happens within days of first flush turbidity events.

FWS' submission, *Technical Staff Comments to the State Water Resources Control Board re: the Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan*, dated 16 August 2012, contains substantial information on entrainment and the influence of turbidity on entrainment. Its annual salvage vs. OMR graphs (USFWS submittal, Figures 5-8, pp. 8-11) indicate that only in 1996, 1999, and 2004 does a discernible pattern exist; however, there is not agreement among the graphs on the level of negative OMR flow that induces higher levels of entrainment. In fact, in 2004 the pattern suggests that strongly positive OMR flow induces higher entrainment. USFWS concludes that there is no particular OMR flow that assures entrainment will or will not occur (USFWS submittal, p. 6, 11). The Deriso (2011) OMR and turbidity trigger analysis is not countermanded by USFWS's submission.

USFWS's submission critiques the Maunder and Deriso (2011) life cycle model results on entrainment effects, suggesting it corroborates the Kimmerer (2008, 2011) contention that entrainment effects may be sporadically significant. USFWS failed to note that the entrainment estimates used in Maunder and Deriso (2011) are based on Kimmerer's 2008

[2] Thomson et al. (2010) found winter exports to be a weak predictor of delta smelt abundance.

paper and extrapolations thereof. Therefore any interpretation USFWS makes about sporadic significance is really a conclusion based on Kimmerer's (2008, 2011) work.

USFWS correctly notes that Kimmerer (2008, 2011) assumes no compensatory density-dependent effects for his entire sequence of years from 1980-2006. This assumption is questionable given that delta smelt abundance was recorded at very high levels during the 1990s. If density dependence exists at high abundance, then several successive high abundance years would effectively "reset" the clock and erase any effect of past abundance patterns. Even ignoring this problem, there are other issues with the Kimmerer (2008) analysis. If the population is at a low level of abundance, then with conventional stock production models, such as the Ricker recruitment model, it is true that substantive compensatory density-dependence is unlikely to be occurring; however, it is also true that natural survival is maximized at a low level of abundance. The long-term equilibrium reduction in a population due to a constant annual mortality (e.g., entrainment) is dependent on the maximum intrinsic rate of growth. For example, in a Ricker model, expressed as $B(t+1) = B(t)(1-F)\exp(a-b*B(t))$, the percent reduction in equilibrium abundance due to a given constant annual mortality "F" is equal to $-\ln(1-F)/a$ (Lawson and Hilborn 1985). The parameter "a" is the maximum intrinsic rate of growth. Note that the long-term equilibrium abundance does not depend on initial population size.

If one were to fit a Ricker stock production model (which incorporates density-dependence) to the years of data analyzed by Kimmerer (2008, 2011) then one would be able to extract the "a" parameter estimate and use the formula provided above to calculate the long-term equilibrium population reduction for a given assumed average entrainment loss. Deriso (2009) did such an exercise using Ricker model parameters obtained by applying the Ricker model to 1987-2006 data (Deriso 2009, Appendix 1) to obtain the estimate $a=0.92$. Taking the same average entrainment loss of 10% as used by Kimmerer (2008, 2011), the long-term equilibrium abundance is calculated to be just 11% lower than if no entrainment occurred. This is far less than the 10-fold reduction in abundance estimated by Kimmerer (2008, 2011).

USFWS also failed to note that, according to Maunder and Deriso (2011), even with no entrainment the population of delta smelt would have been predicted to decline to a very low level of abundance. As stated in Maunder and Deriso (2011): "*Entrainment is estimated to have only a small impact on the adult abundance in either the lowest AICc model, which uses the estimated adult entrainment coefficient and the juvenile entrainment coefficient is zero, or the alternative model, in which both the juvenile and adult entrainment coefficients are set to one*."

USFWS's submittal (p. 30) references Kimmerer (2008) to support its contention that the agreement between Kimmerer's entrainment estimates and particle tracking model (PTM) simulations based on the 20-mm Survey demonstrates that PTM provides a reliable estimate of entrainment for fish inhabiting the San Joaquin River and south Delta. Kimmerer's (2008) results are certainly not evidence that PTM accurately predicts entrainment. As Kimmerer (2008, p. 22-23) himself wrote: "*The variation in annual loss was related to flow conditions …, but this relationship is tautological, since Old and Middle River flow was used explicitly in the calculations*," and "*The relationship of proportional loss to Old* *and Middle River flow (by assumption) and inflow and export flow guarantees a relationship with X2.*" That the PTM tracks OMR flow and Kimmerer's (2008) estimates also track OMR flow is by no means validation for the use of PTM as a predictor of entrainment.

The fact that the delta smelt decline can be explained by environmental covariates and not entrainment is shown in Figure 7 of Maunder and Deriso (2011), reproduced below as Figure 7, where the "alternative model" (right panel) which does not contain entrainment clearly demonstrates.

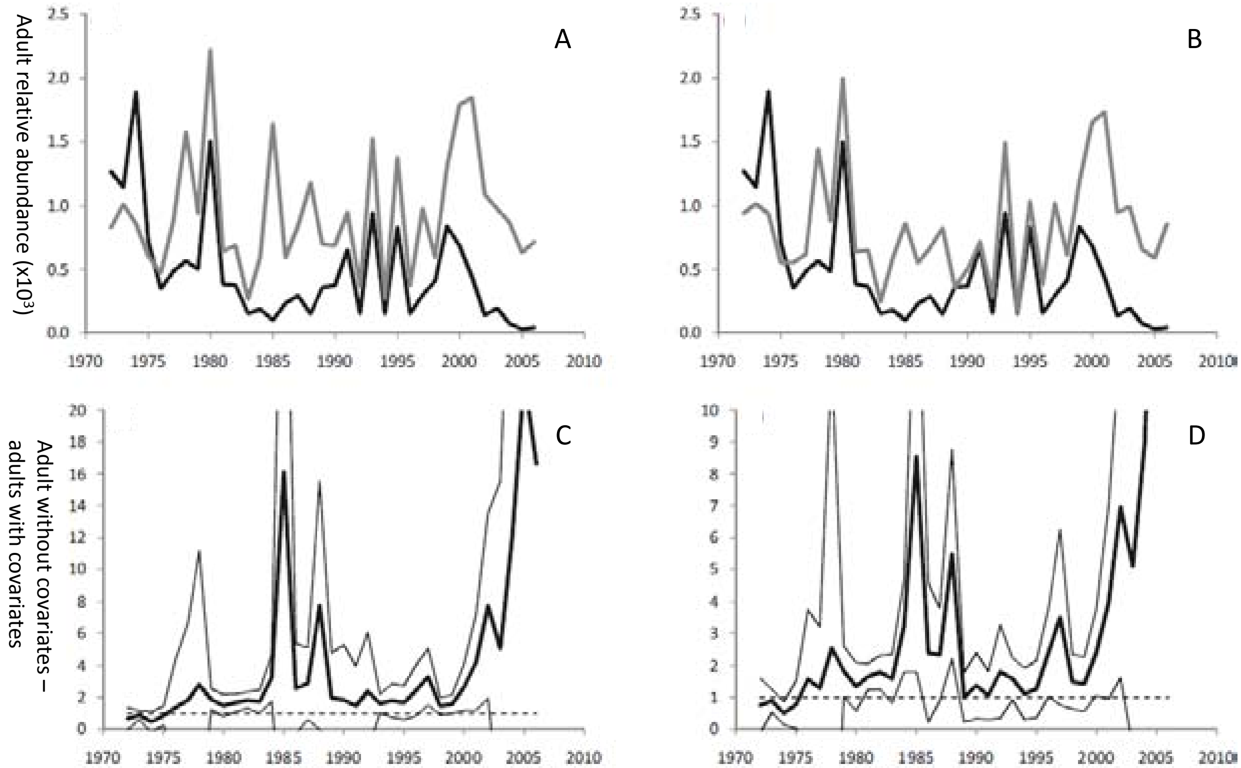

Figure 7. Estimates of abundance with and without covariates (coefficients of the covariates set to zero) (top panels) and ratio of the two with 95% confidence intervals (bottom panels, y axis limited to show details) from the lowest AICc (left panels) model that has Ricker survival from juveniles to adults (black lines) and a Beverton-Holt stock-recruitment relationship (gray lines) and the alternative model (the model that has the fewest covariates and the AIC is less than two AIC units greater than the lowest AIC model) (right panels).

2.4.6 Water Clarity

Thomson et al. (2010) found that changes in water clarity weakly predicted delta smelt abundance. Researchers infer that because delta smelt are thought to have poor vision, turbid water improves visual acuity when seeking out prey (Boehloert and Morgan 1985 in Lindberg et al. 2000; Baskerville-Bridges et al. 2004) and provides some protection from predators (Moyle 2002). Delta smelt appear to prefer turbid waters during all life stages.

It is widely acknowledged that turbidity levels in the estuary have declined. One important causal factor is depletion of the erodible sediment pool by the late 1990s (Schoellhamer 2011). Evidence of depletion is seen in the 36% step decrease in suspended sediment concentration beginning in 1999 (Figure 8).

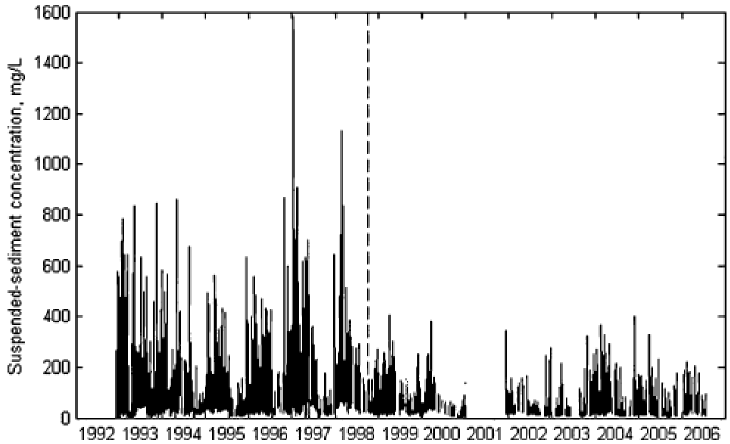

Figure 8. Suspended sediment concentration, mid-depth, Point San Pablo. The vertical dashed line indicates when the step decrease occurred. From Schoellhamer (2011). The decline in suspended sediment is obvious starting in 1999.

Schoellhamer (2011) describes riprapping of the banks of the lower Sacramento River and sediment trapping behind the rim dams and in flood control bypasses as contributors to the decreased sediment supply to the estuary, and notes that the sediment threshold that was crossed in 1999 is coincident with the POD decline that occurred immediately thereafter. Delta smelt require turbid water for successful feeding and predator avoidance (Boehloert and Morgan 1985 in Lindberg et al. 2000; Moyle 2002; Baskerville-Bridges et al. 2004).

Phytoplankton also contribute to turbidity levels. Numerous references in the scientific literature point to filtering of the water column by the Amur River clam *P. amurensis* leading to reduction of phytoplankton standing stock (see, e.g., Carlton et al. 1990; Alpine and Cloern 1992; Feyrer et al. 2003; Kimmerer 2006; Greene et al 2011). While phytoplankton is usually only a small component of suspended particulate matter in the Bay-Delta and northern San Francisco Bay (Cloern 1987; Jassby et al. 2002), invasion by the Amur River clam P*. amurensis* contributed to water clarity of the Suisun Bay region. Analysis of the available data shows that chlorophyll and turbidity levels tracked each other in the summer and fall prior to 1987 (Figure 9).

Absent an erodible sediment pool, the main contributors to turbidity are wind-wave sediment resuspension and rainfall runoff from the watersheds below reservoirs. Wind-wave resuspension is greatest in spring and summer (Schoellhamer 2011) while rainfall runoff is limited primarily to the rainy season. Turbidity pulses are associated with rainfall runoff events (Grimaldo et al. 2009).

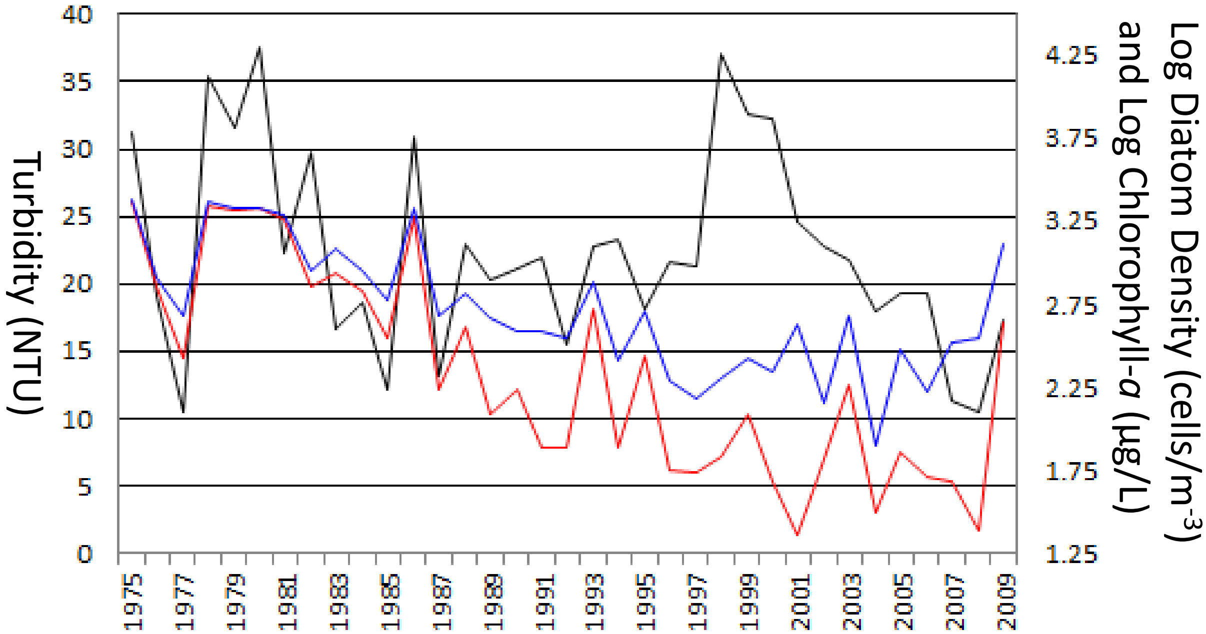

Figure 9. Historical trends in turbidity (black line), diatom density (red line), and chlorophyll-*a* (blue line) for Suisun Bay stations D4, D6, D7, D8. Turbidity and both diatom density and chlorophyll-*a* tracked fairly well until 1988. The pattern has become more divergent since then.

Resuspension is a major source of turbidity levels in both San Pablo and Suisun Bay during the summer, due to reliable onshore winds (Ruhl and Shoellhamer 2004; Ganju et al. 2009; Ganju et al. 2011). The erodible sediment supply is greater in the shallows than in the deeper channels, resulting in greater resuspension in these areas (Ruhl and Schoellhamer 2004). Unlike the Suisun Bay region, which is in an erosion phase (depletion of sediment), the Cache Slough region is in a depositional phase (accrual of sediment) (Morgan-King 2012 IEP Science Workshop). The Cache Slough complex is a backwater region with dead-end channels that trap sediments. The broad shallows are subject to wind-wave resuspension, keeping the region's turbidity at levels satisfactory for delta smelt during all life stages.

2.4.7 Physical Habitat

Hamilton and Murphy (in prep) examined seven environmental attributes and six life stages for selection by delta smelt and found that its habitat includes areas characterized by complex bathymetry (with deep channels close to shallows and shorelines), with little submerged vegetation, but immediately bounded by tidal or freshwater marshlands (which appear to contribute to local production of diatom-rich phytoplankton communities that support adequate levels of delta smelt prey). And, they found that the full array of physical and biotic attributes necessary to consistently support delta smelt, set in spatial context with necessary adjacency and adequate temporal availability, is found in relatively limited areas of the contemporary estuary. Candidate areas for restoration of large emergent wetlands include eastern Montezuma Slough, the Sacramento River below Isleton, and the Cache Slough area. Furthermore, it appears that habitat conditions in areas in north Bay and Montezuma Slough could be improved with channel modifications, and increasing the availability of areas of shallow water in Grizzly Bay, Suisun Bay, and some stretches of the Sacramento River could improve habitat in those areas for young delta smelt.

Less than five percent of the Bay-Delta's historical wetlands and marshlands remain (TBI 1998; Brown 2003). Historically, larger river channels were intermittently connected to nearby intertidal wetlands by a series of distributary channels that occasionally joined the river channels. Diking of distributary channels and conversion of wetlands to agriculture (and, to a lesser extent, urban and suburban development) eliminated most of the connecting distributary channels. The loss of the historical wetlands resulted in significant reductions in allochthonous carbon loading (e.g., from soil and plant material) in the estuary (TBI 1998). Increasing the areal extent of wetlands has the potential to restore at least some of the supply of allochthonous (soil generated) carbon (TBI 1998), which is an important nutrient for the lower trophic levels of the food web. Recognizing the need for additional wetlands habitat, the Bay Delta Conservation Plan anticipates the creation of a significant area of wetlands (BDCP 2012).

2.4.8.1 Conceptual Model Suggesting a Relationship Between the Low-Salinity Zone and Delta Smelt Abundance

The only X2 (low-salinity zone) conceptual model being discussed in recent years relates to a potential relationship between delta smelt abundance and X2 in the fall months. Until perhaps very recently, delta smelt conceptual models have not included spring X2. This has likely been the case because delta smelt are not one of the species with a known abundance relationship with winter-spring outflow (see, e.g., Jassby et al. 1995; Kimmerer 2002; Kimmerer et al. 2009), and because the current Delta Plan already contains spring outflow requirements. To a certain extent, the conceptual models may have changed very recently with the review of the results of the Fall Low-Salinity Habitat (FLaSH) studies, which has resulted in a suggestion that X2 location is biologically important to delta smelt all year, and thereby de-emphasizing fall as a season with special biological meaning. It is premature to consider whether a new conceptual model of a year-round X2 should be considered because the FLaSH study results are preliminary and largely inconclusive (FLaSH, 2012, p. 2). Irrespective of the preliminary FLaSH results, the fishery agencies have thus far only proposed an X2 in the fall months for delta smelt, so that is the only season addressed in detail in this analysis.

The conceptual model regarding fall X2 is described in three papers: Feyrer et al. (2007), Feyrer et al. (2008), and Feyrer et al. (2011). Feyrer et al. 2008 is unpublished but it is relevant to the discussion because a preliminary draft was considered SWRCB Flow Report.

There is new information relating to the fall X2 conceptual model that raises substantial questions about certain statements contained in the SWRCB Flow Report in the following areas: (1) "[t]he amount of habitat available to delta smelt is <u>controlled</u> by freshwater flow and how that flow affects the position of X2 (emphasis added);" (2) there is a demonstrated relationship between fall X2 position and abundance; and (3) the quantity of "habitat" that becomes available to delta smelt when fall X2 is positioned at particular geographic locations provides abundance benefits. (SWRCB Flow Report, pp. 108-110). These statements do not accurately reflect the current state of the science, and would have to be highly qualified and labeled as uncertain and requiring further investigation.

The areas of concern and uncertainty can be summarized as follows:

2.4.8.1.1 The Current Data Does Not Support a Direct Relationship Between the Location of X2 in the Fall and Delta Smelt Abundance

Feyrer et al. (2007) investigated the relationship between certain water quality variables (salinity, turbidity and temperature) and delta smelt occurrence (distribution). Feyrer et al. (2007) also used a stock recruit model to examine the effect of those water quality variables on abundance between the pre-adult stage (FMWT) and subsequent juvenile stage (TNS). The fish abundance data was divided into two separate time periods – 1968-1986 and 1987-2004. For 1987-2004 (but not 1968-1986), incorporating either salinity alone, or salinity in combination with turbidity, improved the fit of the model and explained more of the variance in the data set (Feyrer et al. 2007, pp. 727-728). Using Akaike's Information Criteria, the model with the water quality covariates was preferred.

Feyrer et al. (2008) sought to expand upon the analysis in Feyrer et al. (2007) by chaining together a series of modeled relationships, ultimately linking fall X2 position with abundance. This modeling chained together: (1) water quality variables and presence/absence (or occurrence) of smelt; (2) probabilities of occurrence and quantitative measures of suitable abiotic habitat; (3) suitable abiotic habitat area and X2 position; and (4) suitable abiotic habitat (or X2) and subsequent abundance from pre-adults (FMWT) to juveniles (TNS) the following year (see also Delta Smelt BiOp, pp. 235-236, 268 (Figure E-22)). Feyrer et al. (2008) also developed several future outflow/fall X2 scenarios and modeled the effects of those different scenarios on projected smelt abundance.

The Feyrer et al. (2008) unpublished manuscript was substantially modified and evolved into the Feyrer et al. (2011) article, which was subsequently published. The statistical analysis in Feyrer et al. 2008 had been the subject of quite a bit of scientific debate, which included a critical review in the March 2010 National Research Council Report. The data analysis of fall X2 position and abundance in Feyrer et al. (2008) was ultimately dropped from the Feyrer et al. (2011) article.

This discussion of Feyrer et al. 2007 and 2008 is particularly relevant to these State Water Board proceedings because the SWRCB Flow Report contains the above-described analysis that Feyrer et al. subsequently modified.

2.4.8.1.2 There is Uncertainty Associated With the Method Used to Develop the Fall "Habitat Index"

The revised Feyrer et al. (2008) analysis is contained in Feyrer et al. (2011). This revised analysis linked together multiple relationships, e.g., water quality variables and presence/absence of delta smelt, probability of occurrence and a habitat index, and the habitat index and the average location of X2 in the fall months. The relationship that is proposed in Feyrer et al. (2011) is not a direct relationship between X2 and abundance, as was proposed in Feyrer et al. (2008) (unpublished); it is a relationship between abundance and a habitat index. Feyrer et al. (2011) uses this abundance-habitat index relationship to support the premise that delta smelt habitat carrying capacity has declined as a result of changing X2 position in the fall. Feyrer et al. (2011) concluded that the habitat index was reduced from 1967 through 2008, and under certain future development and climate scenarios. There are several uncertainties associated with the analysis as presented in Feyrer et al. 2011.

2.4.8.1.2.1 Data Analysis Is Circular

The relationship between X2 and abundance in Feyrer et al. (2011) depends on a correlation between Feyrer et al.'s habitat index and FMWT abundance. This correlation is graphically shown in Figure 2C of Feyrer et al. (2011); however, this correlation appears to be an induced correlation. The habitat index was constructed using FMWT abundance data and then the habitat index was correlated against FMWT abundance. Consequently, both the X and the Y axes of the graph use a common data set. When the same data are being compared on both axes, some degree of statistical correlation will be induced.

The habitat index:FMWT correlation should therefore be evaluated in light of the potential for induced correlation. Dr. Ken Burnham has estimated that the induced correlation could lead to a baseline correlation of R^2=0.56. Feyrer's habitat index:FMWT correlation has an R^2=0.51, which suggests that the correlation between the habitat index and FMWT could be almost entirely induced.

2.4.8.1.2.2 Data Analysis Did Not Include Cache Slough Abundance Data

Feyrer et al.'s (2011) analyses did not include the delta smelt residing wholly in freshwater in the Cache Slough region. The FMWT did not begin sampling in the Cache Slough region until 2009. Feyrer et al.'s water quality:presence/absence analyses were all done using FMWT data before that survey began sampling in the Cache Slough region (Feyrer et al. 2007 used FMWT data up to 2004; Feyrer et al. 2008 used data up to 2006; Feyrer et al. (2011) used data up to 2008). Since the Feyrer et al. conceptual model is that salinity is the driver of delta smelt distribution, not using the data from fresher areas, particularly the Cache Slough region where a large segment of the population reside, may have affected the results of the data analysis.

Delta smelt inhabit the Cache Slough region year-round; their presence there is not a sampling artifact (Sommer et al. 2011; Delta Science Program Science News, April 2010).

The size of the delta smelt population in the Cache Slough region is substantial, comprising as much as 42% of the current monitoring catch since 2005 (Sommer et al. 2009; Huggett 2010). Sommer et al. (2009) also noted that delta smelt in the Cache Slough region are "a fairly substantial portion of the population as about 42% of the Spring Kodiak Trawl delta smelt catch during March-May since 2005 was in the Cache Slough complex". Hamilton et al. (in press)recognized that the data suggest that the delta smelt population in Cache Slough may be a separate subunit of the population, and that current fish abundance surveys may not be sampling the full range of the species. Nearly 60% of the delta smelt captured in the 2011 Summer Townet Survey were collected in the Cache Slough Complex. (Osborn 2012).

2.4.8.1.2.3 The Feyrer et al. Studies Focused on Abiotic Variables

The Feyrer et al. analyses only consider three abiotic variables – salinity and turbidity (Secchi depth) – and excluded all of the other abiotic and biotic variables that make up a species' habitat and affect its abundance. The Feyrer et al. (2007) article acknowledged that biotic variables such as predation, food supply, and competition played a major role in distribution and habitat of smelt, but these variables were not included in the analysis.

2.4.8.1.2.4 Life Cycle Modeling Shows That the Location of Fall X2 Has No Significant Effect on Delta Smelt Abundance

Several life cycle or multi-variable models have been conducted to try to explain the abundance patterns of delta smelt, including the fall season.

Thomson et al. (2010) used change-point analysis to investigate step changes in nearly two dozen candidate environmental factors which they surmised might have corresponded with the dramatic drop in delta smelt numbers that was sustained for much of the past decade, including the mean location of X2 in the fall months. No signal of effects on delta smelt from the location of X2 in the fall months was identified.

MacNally et al. (2010) used multivariate autoregressive modeling to evaluate 54 fish-environmental factor relationships, including the factors considered by Thomson et al., and found generally weak relationships, but enhanced signals from food availability and the position of the low-salinity zone in the spring.

Maunder and Deriso (2011) used a multistage life-cycle model that varied levels of presumptive density dependence to consider environmental factors acting on delta smelt abundance and found a substantive deterministic relationship to be the availability of the fish's food resources. The location of X2 in the fall months was not found to be a predictor of delta smelt abundance.

The environmental data in that study were shared in a multi-variable regression analysis by Miller et al. (2012), who asserted that their specification of environmental variables was spatially and temporally rectified to better reflect within-Delta patterns of environmental variation. They found food availability to be a major signal and predation and entrainment to be minor signals, with overarching effects from density dependence.

Like Thomson et al., none of the latter three studies found evidence of a relationship between the location of X2 in the estuary in the fall months and delta smelt abundance. There is no evidence that can be drawn from those studies of environmental stressors to support the link between the location of X2 in the estuary in the fall months and trends in delta smelt population numbers.

Because the location of the low-salinity zone in the estuary has only a weak spatial relationship with the extent and quality of delta smelt habitat (NRC 2012), and because there is no established connection between the location of the low-salinity zone in the estuary and the abundance of delta smelt (Thomson et al. 2010; MacNally et al. 2010; Maunder and Deriso 2011; Miller et al. 2012), the central premise of the fall X2 conceptual model has not been supported. Therefore, the two critical assertions of the Feyrer papers – that the location of the low-salinity zone in the estuary is linked to delta smelt population size (or performance or production) and that the extent of the low-salinity zone functionally represents the extent of habitat for delta smelt – deserve closer examination.

2.4.8.1.2.5 The Conceptual Model Suggesting a Biological Rationale for Locating the Position of X2 near Suisun Bay Has Not Been Sufficiently Investigated

The fall X2 conceptual model is based on the idea that the action will redistribute delta smelt downstream into Suisun Bay, thereby increasing opportunities for feeding and rearing (USFWS 2008). This model further contemplates that the redistribution of delta smelt downstream into Suisun Bay in the fall months will reduce the vulnerability of the fish to predation (USBR 2011). Available data do not support the conceptual model. The data do not reflect a relationship between the location of X2 in the Sacramento-San Joaquin Delta and the population dynamics of delta smelt or the location and extent of the low-salinity zone and the extent of suitable habitat for the delta smelt.

The conceptual model suggesting that Suisun Bay is the optimum habitat for delta smelt is contrary to an earlier conceptual model that Suisun Bay is a poor habitat area for delta smelt (the so-called "bad Suisun Bay" model). The bad Suisun Bay model became one of two conceptual models favored several years ago (Jones and Stokes 2006; Armor et al 2007; House Committee on Resources 2007). It also appeared in the Interagency Ecological Program's 2006-2007 POD work plan and its 2005 POD synthesis report. The conceptual model recognized that non-native species are causing detrimental changes to the Suisun Bay food web. Among those, the Amur River clam has had the largest known effect, greatly reducing primary production (see PWA submittal, *Ecosystem Changes to the Bay-Delta Estuary: A Technical Assessment of Available Scientific Information*, dated 16 August 2012, pp. 2-20). Introductions of various zooplanktons eaten by young fishes have further changed the pathways from primary production to fish (Baxter et al. 2010; Gould and Kimmerer 2010). Due to these known changes, and possibly others, the bad Suisun Bay conceptual model posits that Suisun Bay is a less suitable nursery than it used to be. The current fall X2 conceptual model based on work by Feyrer et al. (2007, 2011) does not consider food availability or quality. The PWAs' submittal, *Ecosystem Changes to the Bay-Delta Estuary: A Technical Assessment of Available Scientific Information*, dated 16 August 2012, pp. 2-2 to 2-42, describes changes to the Delta's and the low-salinity zone's food web and how these have cascaded from primary productivity to higher trophic levels.

2.4.8.1.2.6 The Conceptual Model Suggesting That the Low-Salinity Zone Should Be Located in Any Particular Location is Based on the Model That Delta Smelt Distribution Changes in Relation to the Low-Salinity Zone

The monitoring data does not necessarily support the conceptual model that delta smelt are distributed in relation to the low-salinity zone or that the delta smelt population's distribution can be changed by moving the low-salinity zone downstream.

Distributional data demonstrate that delta smelt inhabit areas of the estuary that are characterized by a wide range of salinity from freshwater to 10 psu and higher. Further, a recent affinity analysis[3] (Hamilton and Murphy in prep) finds that the species is not limited by salinity and flows to the areas it occupies. Rather, other environmental factors define delta smelt habitat and the survival and future recovery of the species in the estuary. Delta smelt are found across the entire northern delta, in far western portions of Grizzly and Suisun bays that are characterized by higher salinity conditions, and east to areas beyond Cache Slough where tidal exchanges give way to fresh water on the lower Sacramento River (Merz et al. 2011). Survey returns for multiple life stages of delta smelt have now been analyzed with time-series data drawn from a collection of environmental factors in an effort to provide guidance to habitat conservation planning (Hamilton and Murphy in prep). Those analyses offer contingent explanations for patterns of delta smelt presence and absence in specific areas, and they show that delta smelt have the ability to seek out habitat and maintain presence in suitable locations across a wide range of salinity conditions and the broadest fluctuating seasonal flow scenarios. Delta smelt habitat requirements (more exactly, the physical and biotic conditions required for delta smelt presence) are multi-dimensional and for some environmental attributes of the Delta vary with life stage, reflecting the fact that smaller, younger fish have different resource needs and ecological tolerances than larger, more mature fish, and spawning fish seek out areas of the Delta not used by juveniles and pre-spawning adults. Maps of the distribution of delta smelt in the estuary offer insights into delta smelt habitat requirements that are salient to planning for restoration of habitat for the species (Figure 10). Larval and juvenile fish are found throughout the Sacramento River, while pre-spawning and spawning fish are found in fresher water circumstances, such as Suisun Marsh, Cache Slough, and portions of the lower Sacramento River.

Broad parts of the estuary exhibit salinity conditions that are acceptable for delta smelt in all water years and under all contemporary flow regimes (Sommer and Mejia in review). But, while salinity and flows have negligible contributions to delta smelt habitat suitability, the same distribution data indicate that large portions of the estuary are frequently unsuitable for delta smelt, particularly in the south and southeast Delta, where summer and fall water conditions can be too warm and too clear, and hence are unoccupied by delta smelt (Nobriga et al. 2008).

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[3] Affinity analysis in the biological sciences is widely used to examine habitat and species relationships (see, e.g., Deri et al. 2010). It is a data analysis and data mining technique that discovers co-occurrence relationships among activities performed by (or recorded about) specific individuals or groups. In general, this can be applied to any process where agents can be uniquely identified and information about their activities can be recorded.

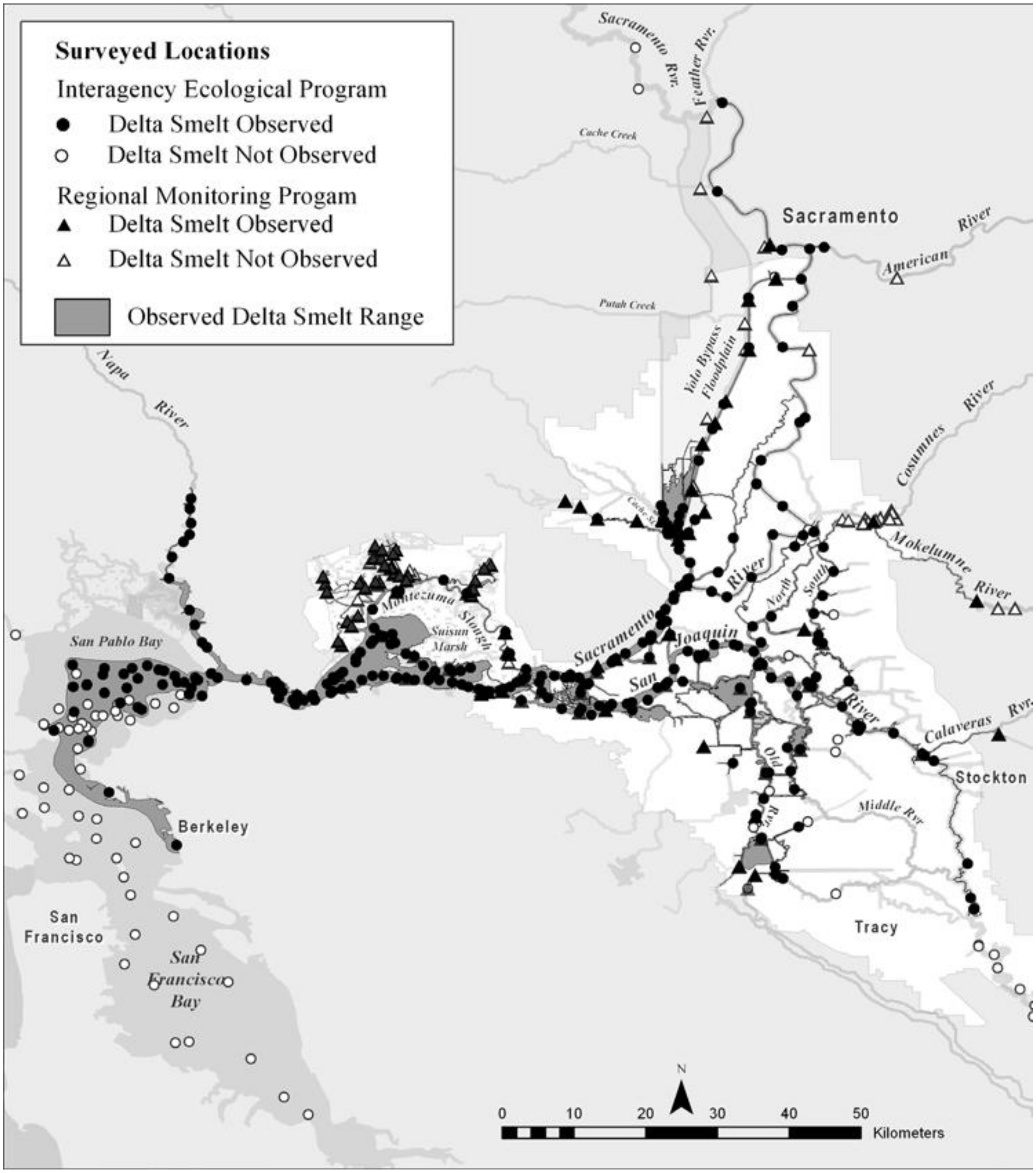

Figure 10. Distribution of delta smelt across all regular fish monitoring surveys. From Merz et al. (2011), based on presence/absence of delta smelt. In all surveys, delta smelt are found across a broad range of the estuary.

2.4.8.1.2.7 Before X2 Can Be Used as a Surrogate for Delta Smelt Habitat Analyses Are Needed That Establish the Appropriateness of Using a Surrogate

While Feyrer et al. (2007) noted that “other factors,” including several biotic and abiotic factors noted above, contribute to delta smelt habitat, and the delta smelt biological opinion recognized that multiple resources and other environmental factors contribute to the survival and recovery of delta smelt, the location of X2 in the estuary in the fall months is nonetheless used as a "surrogate" for delta smelt habitat for purposes of water management planning (USBR 2011). Because the extent of open waters is greater in western, downstream areas of the estuary, when X2 is located in those downstream areas the low-salinity zone is more expansive; hence, according to Feyrer et al. (2011) more habitat is available to support delta smelt. But, cannot justify using a surrogate for delta smelt habitat, rather than considering the full range of delta smelt habitat factors, until an analysis has been completed that supports using a surrogate.

An ecological indicator or management surrogate is an environmental attribute that responds to relevant ecological conditions in a manner similar to a target species or its habitat, where direct data for the species or its habitat are too difficult, inconvenient, or expensive to gather (see Landres et al. 1988; Caro 2010). Default to inference from indicators or surrogates in natural resources management has intuitive appeal, particularly in the case of delta smelt, given its elusive behavior and residence in turbid waters that obscure its interactions with its environment, making it especially difficult to observe or census. It is standard practice for wildlife and fisheries managers to determine whether the presence of an indicator or surrogate accurately predicts the presence of the target before employing such planning proxies in management practice (Caro et al. 2005; Wenger 2008). The published literature cautions against using a surrogate without proper analysis establishing the appropriateness of the practice (Landres et al. 1988; Noon et al. 2005; Cushman et al. 2010).

There are three criteria that an ecological indicator must fulfill to establish its validity, and ultimately its utility, for use as a surrogate that can represent habitat for a species in the context of conservation planning:

1) the indicator must spatially and temporally occur over much of the geographic range of the target species and the distribution of its habitat;

2) there must be an ecological mechanism by which the indicator controls or affects the distribution or abundance of the species, or extent or condition of its habitat;

3) the status of the indicator must be anticipatory of changes in the status of the species or its habitat; that is, a measurable change in the indicator will predict changes in population numbers or habitat conditions that can be averted by management action.

(consistent with Hunsaker et al. 1990; Dale and Beyeler 2001; Niemi and McDonald 2004.)

Use of the location of X2 in the fall months as an indicator of the extent of habitat for delta smelt does not satisfy the above criterion. An effective surrogate measure for delta smelt habitat must exhibit a high degree of spatial and temporal overlap with the distribution of delta smelt. Delta smelt can be found at salinities substantially greater than 10 psu, as much as five times the X2 concentration and well outside the 0.5-6 psu range often used to describe the low-salinity zone (see, e.g., Baxter et al. 2010). Moreover, delta smelt are found in substantial numbers in near-freshwater portions of the estuary in upstream areas unaffected by the location of the X2 isohaline. Furthermore, large portions of the estuary that experience X2 and near-X2 conditions are not occupied by delta smelt in the fall months and have not been occupied during most of the past decade. Those areas appear not to be suitable for delta smelt, either because of inadequate turbidity conditions or seasonally excessive temperatures (Hamilton and Murphy, in prep.); hence, despite acceptable salinities, those extensive areas do not serve as habitat for delta smelt. Accordingly, on the one hand, the low-salinity zone, as described in the biological opinion, does not include significant areas of delta smelt habitat and, on the other hand, much of the low-salinity zone frequently does not support delta smelt. It therefore cannot be said that the low-salinity zone serves as "core habitat" area for the species, as suggested by Feyrer et al. (2007, 2011).

2.4.8.1.2.8 Summer Townet Survey for 2012 Would Not Have Been Predicted by the Feyrer et al. (2007) Equation

The Feyrer et al. (2007) fall X2 model is based on a predictive stock-recruit relationship between the FMWT of one year and the succeeding Summer Townet Survey, with the average location of X2 in the fall months used as a covariate (USFWS 2008, 2011). Using the Feyrer et al. model, the average position of X2 in the fall months of 2011 would be expected to produce a Summer Townet Survey index in 2012 of 7.99. The recently published Summer Townet Survey index for delta smelt is 0.9, which is far lower than would be predicted by Feyrer et al. (2007). That the prediction is off by an order of magnitude does not necessarily invalidate the fall X2 hypothesis; however, it does suggest that something else is contributing to delta smelt abundance. In addition, it raises significant uncertainty with respect to the utility of the fall X2 hypothesis for management purposes.

2.4.8.1.2.9 Fall X2 Has Not Been Trending Upstream

The fall X2 conceptual model is premised on a belief that there has been a continual increase in salinity (i.e., X2 moving upstream or east) since 1967; however, the years selected for the analysis influenced the results. By choosing the years 1967-2004, the agencies compared a very wet period to a very dry period. Whenever specific years within the hydrological record are selected for analysis, it is important to account for hydrology to avoid interpreting results that are purely hydrology driven as a change in water consumption.

As explained by Dr. Paul Hutton during the PWAs' oral presentation on ecosystem changes and the low-salinity zone on 16 August 2012, a statistically significant long term (water years 1922-2011) trend in X2 position shows that the Delta has been getting fresher in September. X2 position does not show a statistically significant long term trend upward or downward in October. Dr. Hutton noted that, although fall X2 position has been higher in recent decades, it is comparable with conditions observed prior to construction of Shasta Dam. It is possible that higher fall X2 positions in recent decades correspond to deepening of the estuary's main channels due to erosion, which would increase gravitational circulation allowing higher salinity bay waters to intrude farther into the Delta.

2.4.8.1.2.10 Summer X2 Conceptual Model Has Not Been Investigated and the Preliminary Data Does Not Suggest That Summer Has Particular Biological Importance

The California Department of Fish and Game's submittal, *Written Information Responsive to the Workshop Questions for the Bay-Delta Workshop 1 - Ecosystem Changes and Low Salinity Zone*, dated 16 August 2012, suggests that the State Water Board consider flow objectives for summer as well as fall. If scientific information emerges during the process of updating the Bay-Delta Plan indicating that summer low-salinity zone position is important to juvenile survival (p. 3), it should be noted that Nobriga et al. (2008), the only published study testing a summer X2 conceptual model, performed essentially the same analysis as Feyrer et al. (2007) except using the Summer Townet Survey rather than the FMWT. As a result, many of the same uncertain methodological approaches that are made by Feyrer et al. (2007) are repeated in Nobriga et al. (2008), including but not limited to use of X2 as an unverified surrogate of delta smelt habitat, induced correlation, and using a limited number of abiotic and biotic characteristics of actual delta smelt habitat. To its credit, Nobriga et al. (2008) did not limit its analysis to the post-1987 period. Nobriga et al. (2008) performed spatial (entire upper estuary and three regions) linear regression analyses of salinity, Secchi depth, and water temperature against relative abundance of delta smelt using the Summer Townet Survey; however, salinity was not found to be a significant predictor for any region either in terms of its predictive power (R^2-value) or level of statistical significance (p-value). Therefore, Nobriga et al. (2008) offers little guidance to the State Water Board in considering modifications to the Bay-Delta Plan.

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3.0 Other Pelagic Organisms

This chapter addresses additional fishes and other pelagic organisms. For each of the species, there is considerable uncertainty as to whether additional reservoir releases or Delta through flows can achieve desired ecological functions. For some species, available survey data suggests that additional flow-based actions are unsupported.

A brief summary of factors the State Water Board should consider when evaluating the need for Delta through flows for other pelagic organisms include:

- Green sturgeon: There is currently little or no scientific basis that any specific action, such as further modifications of water project operations, will produce negligible, limited, or substantial benefits. Due to a fundamental lack of information and the status of green sturgeon and the factors that limit its numbers, additional research is an essential prerequisite to the identification of additional actions.

- Splittail: No flow-related actions are supported by the scientific literature. The literature supports actions intended to increase the availability of floodplain rearing and spawning habitat for splittail and other fishes, including physical modifications to the Fremont Weir and Yolo Bypass to manage the timing, frequency, and duration of inundation of the Yolo Bypass with gravity flow from the Sacrament River, and to improve upstream fish passage past barriers that include Fremont and Lisbon weirs.

- Starry flounder: Based on the Bay Study Otter Trawl data from the past three decades, starry flounder is not experiencing a decline in abundance in the San Francisco estuary. There is no scientific justification for the State Water Board to take any further actions to maintain the abundance of the fish.

- American shad: American shad is a bay fish that spawns upstream in larger rivers; it is not an estuarine fish. Its weak relationship with the position of X2 in the Delta is likely an artifact of physical circumstances that co-vary with inter-year variation in Delta through flows. Similar to Chinook salmon, the use of the Delta by American shad is primarily a just-passing-through phenomenon on directional downstream migration to salt waters. The scientific literature does not support additional flow-based actions.

- Northern anchovy: The central stock of northern anchovy is not experiencing a decline.

- Striped bass: In spite of the effects of density dependence during their young juvenile stage, sufficient numbers of age-0 fish appear to be recruiting into the adult population. Likewise, recreational catch, the CDFG's designated beneficial use for striped bass, has not declined.

California bay shrimp: Based on the Bay Study Otter Trawl data, California bay shrimp is not experiencing a decline. There is no reason to believe that further actions are needed to maintain its abundance.

3.1 Green Sturgeon

3.2 Summary and Introduction

The green sturgeon is an anadromous species that spawns in the main stem of the Sacramento and Feather rivers, and matures over the first few years of life in the Sacramento-San Joaquin Delta prior to emigrating to the ocean and large coastal bays where it spends most of its life (Beamesderfer et al. 2007). The more numerous white sturgeon, *Acipenser transmontanus*, is also present in the system.

Green sturgeon in the San Francisco estuary were listed on April 7, 2006, as threatened under the Endangered Species Act (ESA) by the National Marine Fisheries Service (NMFS) (71 FR 17757). The listing includes only the southern distinct population segment (DPS), which includes only the single Central Valley population. Green sturgeon from the northern DPS, occurring in coastal California and Oregon rivers from the Eel to the Umpqua, was not listed under the ESA.

Information on the historical and current distribution and status of green sturgeon in California's Central Valley is sparse. These fish were listed due to: (1) the concentration of spawning into one river system, which serves to increase the risk of catastrophic events causing extinction; (2) apparent loss of spawning habitat due to migration barriers; (3) suspected small population size (acknowledging a general lack of population data); and (4) exposure to a variety of direct and indirect risk factors related to widespread ecosystem alteration and suspected loss of habitat.

Critical Habitat was formally designated by NMFS on September 3, 2008, in freshwater, marine, and coastal bay and estuary areas inhabited by green sturgeon (73 FR 52084). In fresh water, those include the Sacramento River upstream to Keswick Dam, the Yolo and Sutter bypasses, the lower Feather and Yuba rivers, and the Sacramento-San Joaquin Delta. Coastal marine waters included areas within 110 m depth from (and including) Monterey Bay north to the U.S.-Canada border. Coastal bays and estuaries included San Francisco, San Pablo, Suisun bays, and seven additional bays or estuaries between Humboldt Bay, California and Grays Harbor, Washington.

NMFS has convened a green sturgeon recovery team and is in the process of developing a formal recovery plan; however, specific measures for conservation and recovery of this species have not yet been articulated.

3.3 Green Sturgeon Biology

Green sturgeon, *Acipenser medirostris*, are an ancient but elusive species that spend most of their lives in marine waters along the continental shelf from northern California to southern Canada (Moyle 2002). Like all sturgeon, they are long-lived and reach large sizes. Ages of 60-70 years are likely and sizes up to eight feet and 400 pounds have been recorded. Sexual maturity typically occurs at 15 to 25 years of age and four to five feet in length. Green sturgeon are bottom-oriented feeders and eat a variety of invertebrates and fish.

Spawning occurs at specific sites in the main stem Sacramento River between Hamilton City (mile 199) and Keswick Dam (mile 301). Adults are occasionally observed in the Feather River and spawning was documented there in 2011. Moyle et al. (1992) surmised that spawning may take place or once did in the lower San Joaquin River; however, there is currently no direct evidence of green sturgeon occurrences or spawning in the San Joaquin River upstream from the Delta (Adams et al. 2002; Beamesderfer et al. 2004, 2007).

Only a portion of the adult population spawns in any year, but green sturgeon return to spawn in the Sacramento River every year (see Figure 11). Due to their large size, female sturgeon are very fecund and can produce large numbers of offspring under favorable conditions. The success of spawning and subsequent survival varies considerably from year-to-year due to environmental conditions. The long sturgeon life span is adapted to accommodate episodic recruitment; green sturgeon abundance appears to fluctuate over time in response to intervals of high and low recruitment.

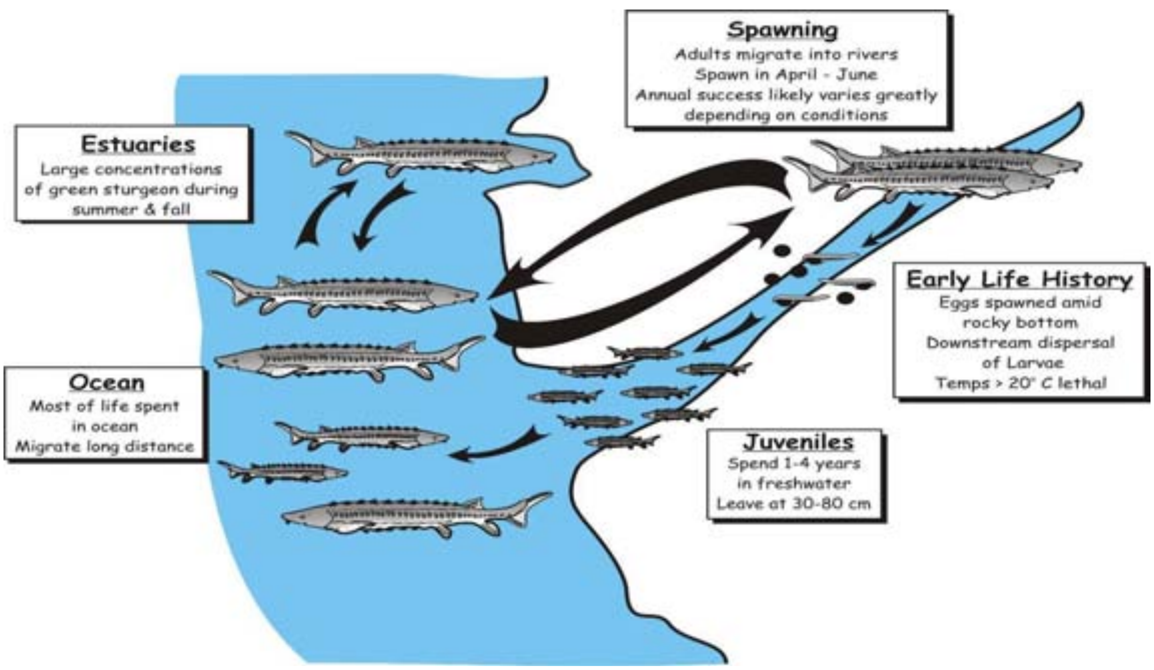

Figure 11. The green sturgeon life cycle. From Beamesderfer et al. (2007).

The Delta and other areas, including San Francisco, San Pablo, and Suisun bays, provide important rearing habitat for juveniles and sub-adults, and areas through which sub-adults and adults migrate (Adams et al. 2002; NMFS 2009).

3.4 Environmental Factors Affecting Green Sturgeon

Factors currently limiting green sturgeon status are poorly understood. While a variety of potential limitations have been identified, the population-scale impacts of specific factors have not been quantified. Known or suspected limiting factors identified by NMFS (Adams et al. 2002, 2007; NMFS 2005, 2008) include:

3.4.1 Impassable Dams

Upstream migration is blocked at Keswick and Shasta dams on the Sacramento River and the Fish Barrier and Oroville dams on the Feather River. Areas upstream from these barriers are believed to have historically supported green sturgeon spawning (Mora et al. 2009).

3.4.2 Migration Barriers

A number of structures may impede upstream migration of adults under certain conditions. Red Bluff Diversion Dam historically blocked migration during the irrigation season when control gates were in place; however, 2011 was the last year of gate operation. Adults can be attracted into the Yolo Bypass in high flow years and may become stranded below the Fremont Weir. The Delta Cross Channel gates may impede passage under certain conditions. Shanghai Bench and the Sunset Pumps diversion appear to impede passage in the lower Feather River under low-flow conditions.

3.4.3 Fishing Impacts

Because of their long life span and delayed maturation, sturgeon are very susceptible to overfishing. California sturgeon populations collapsed due to unregulated commercial fishing prior to 1900; numbers gradually increased over the next century. Sport fisheries for green sturgeon in California and commercial fisheries for green sturgeon in Oregon and Washington have been closed following listing. Fish are still subject to incidental handling in various fresh water and marine, sport and commercial fisheries, and illegal harvest occurs in fresh water during spawning migrations.

3.4.4 Water Diversions

Entrainment and impingement by water diversions has been identified as a threat, but the degree to which those factors affect the abundance of green sturgeon or the continued existence of the Southern DPS remains uncertain (71 FR 17757). Variable numbers of juvenile sturgeon are seen in fish salvage at the CVP Tracy and SWP Skinner Fish Collection Facilities in some years (Figure 12). Salvage estimates of green sturgeon numbered in the hundreds or thousands until the 1980s, but have averaged fewer than 100 green sturgeon per year since that time.

3.4.5 Flow and Temperature Effects

Insufficient flow and high water temperatures were identified by NMFS as risk factors but specific information on the significance of these factors to green sturgeon abundance and the continued existence of the species is lacking (NMFS 2009). Water temperatures of less than 20°C (68°F) are required for successful spawning and egg incubation (Beamesderfer et al. 2007 and references therein). Unfavorable temperatures for spawning and egg incubation were historically documented downstream from Shasta Dam, but have been ameliorated by temperature controls. Recruitment of white sturgeon in some populations has been correlated to stream flows during spring (Duke et al. 1999). Attempts to regulate

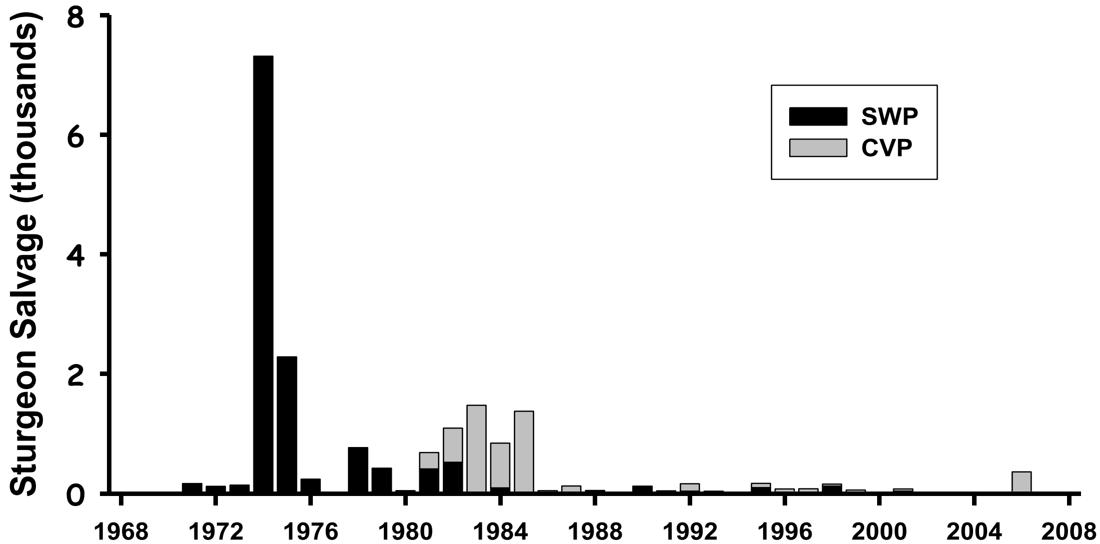

Figure 12. Estimated annual salvage of green sturgeon at State Water Project (SWP) and federal Central Valley Project (CVP) fish facilities in the South Delta. Data from California Department of Fish and Game.

flows to improve recruitment of white sturgeon in Pacific Northwest populations have been unsuccessful. The mechanism(s) by which flow affects green sturgeon is unclear.

3.4.5 *Ecosystem Changes*

Large-scale ecological changes in the Delta ecosystem have resulted from a combination of physical landscape changes, food web alteration, and exotic species introductions. NMFS has identified exotic species as potential risk factors, and speculated on predation by striped bass. The net impact of multiple ecosystem changes on green sturgeon is uncertain and likely complex. Notably, the point at which the food web in the estuary was substantially modified by the proliferation of the Amur River clam coincided with the decline in green sturgeon juveniles as indexed by water-project salvage numbers, suggesting that ecosystem changes could have a significant impact upon population abundance.

4.0 Sacramento Splittail

4.1 Introduction and Summary

Meng and Moyle (1995) concluded that the geographic range of splittail had been reduced to a fraction of its former extent; attributing this to a loss of low-salinity habitat in Suisun Bay and Suisun Marsh. Based on Meng and Moyle (1995) and other sources, the USFWS took action to list the splittail as a threatened species in 1999. Since then, it has been determined that splittail's range is greater than was previously thought (USFWS 2010). Subsequent wet years with significant floodplain inundation events caused its abundance to rebound, leading to a remanding of its threatened status in 2003, and eventual reversal of its listing under the federal Endangered Species Act in 2010.

Entrainment of splittail in the fish collection facilities increases in hydrologically wet years when floodplain inundation events result in a spike in population size and decreases during hydrologically dry years when recruitment is low (Sommer et al. 2007). No evidence is available that indicates that water project operations have a significant effect on splittail population size and trends (Sommer et al. 2007).

The abundance of age-0 splittail has not shown a discernible change in either adult or juvenile abundance after 1987, the point at which the food web in the estuary was substantially modified by the proliferation of the Amur River clam *P. amurensis* (Sommer et al. 1997; Kimmerer 2002).

No flow-related actions are supported by the scientific literature. The literature supports actions intended to increase the frequency and persistence of Yolo Bypass inundation.

4.2 Sacramento Splittail Biology

Sacramento splittail, *Pogonichthys macrolepidotus,* is a native cyprinid that can live 8-10 years (Moyle 2002). Splittail are physiologically hardy and able to tolerate a relatively wide range of temperature, salinity, and dissolved oxygen levels (Young and Cech 1996), including a broad tolerance for salinities of 10-18 psu, which avails them to slow moving sections of rivers and sloughs in the Delta (Moyle 2002; Moyle et al. 2004). Their range encompasses much of the Delta tributaries below the major rim dams, the lower Napa River, and the lower Petaluma River, where a self-sustaining population apparently exists (Moyle 2002; Sommer et al. 2007, 2010). The Sutter and Yolo Bypasses are apparently important spawning areas (Moyle 2002). In the Delta, they are most abundant in the north and west when populations are low, but are more evenly distributed in years in which they realize high reproductive success. The opossum shrimp *N. mercedis* is an important food resource for splittail, although after the invasion of the Amur River clam their diet has increasingly focused on bivalves and amphipods (Sommer et al. 2007). While on floodplains, aquatic invertebrates, such as chironomid midge larvae, make up the largest portion of their diet (USFWS 2010).

Splittail use inundated floodplains in spring as spawning habitats (Sommer et al. 1997; Moyle 2002), requiring flooded vegetation for both spawning and rearing. Strong year classes are associated with wet-year inundation events (Sommer et al. 2007), with the abundance of age-0 fish being relatively low during dry years (Figure 13). Floodplain inundation represents the primary factor that determines spawning success (Sommer et al. 1997). When the combined flow of Sutter Bypass and the Sacramento and Feather rivers raises water levels at Fremont Weir to an elevation of 32.8 feet (which typically occurs when combined total flow from these sources surpasses 55,000 cfs), flows begin to enter Yolo Bypass (BDCP 2012). Adults begin a gradual upstream migration towards spawning areas sometime between late November and late January (Moyle et al 2004). As floodplains drain down, a downstream dispersal phenomenon occurs.

4.3 Environmental Factors Affecting Sacramento Splittail

The most significant factor predicting splittail abundance is the availability of inundated floodplain over a sufficient amount of time to allow for successful spawning and rearing. Feyrer et al. (2006) noted that manipulating flows entering Yolo Bypass, such that floodplain inundation is maximized during January-June, might provide the greatest overall benefit for splittail, especially in relatively dry years when overall production is lowest. Inundation for at least a month appears to be necessary for a strong year class of splittail (Sommer et al. 1997).

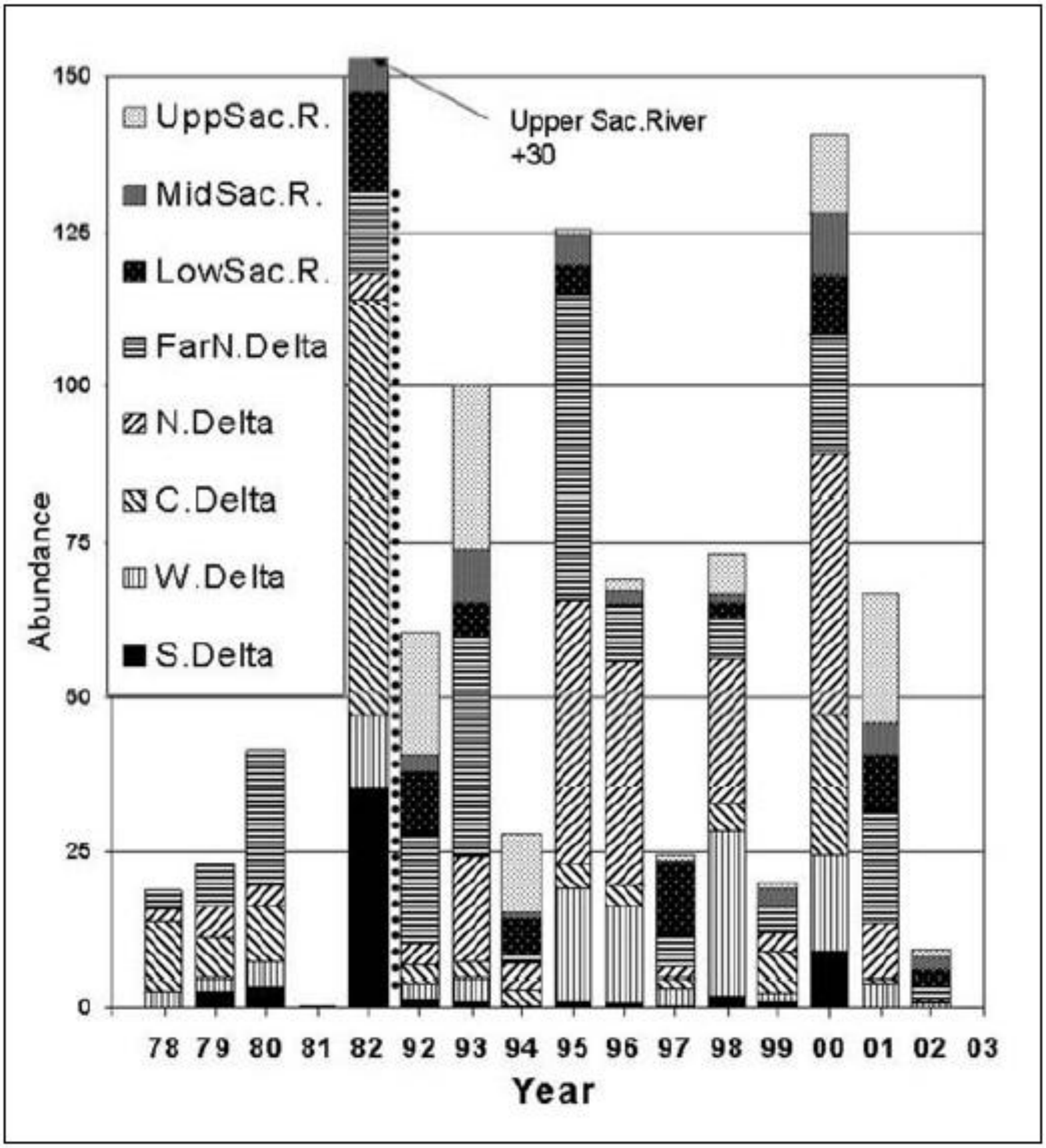

Figure 13. Age-0 splittail (>24 mm FL) abundance and distribution based on U.S. Fish and Wildlife Service beach seine survey, 1978-1982, 1992-2002. Data are mean catch per haul by region for May and June. Regions follow Sommer et al. (1997), except for those upstream of the Delta: (1) lower Sacramento River ("LowSac.R"—Feather River [river kilometer 129] to American River [river kilometer 97]); (2) middle Sacramento River ("MidSac.R."—Butte Creek [river kilometer 222] to Knights Landing [river kilometer 145]); and (3) Upper Sacramento River ("UppSac.R."—Ord Bend [river kilometer 296] to Colusa State Park [river kilometer 239]). Sampling in the latter three regions began in 1981. From Sommer et al. (2007).

5.0 Starry Flounder

5.1 Introduction and Summary

Since 2002, the starry flounder abundance index has been from 300-500. Based on the Bay Study Otter Trawl data from the past three decades, starry flounder is not experiencing a decline in abundance in the San Francisco estuary. There is no scientific justification for the SWRCB to take any further actions to maintain the abundance of the fish.

5.2 Starry Flounder Biology

Starry flounder, *Platichthys stellatus*, is a flatfish found along the Pacific Coast from Santa Barbara County northward to the Alaskan Peninsula (Wang 1986). In the Bay-Delta estuary it is one of the most common flatfish found (Wang 1986). It is a fish of San Francisco Bay that can survive in fresh water – it has been observed in San Luis Reservoir, arriving there via transport in the California Aqueduct or San Luis Canal (Moyle 2002) – making some use of the lower Delta for rearing of young. Spawning occurs in late fall and early spring months in shallow coastal waters or tidal sloughs (e.g., Elkhorn Slough) (Wang 1986). Young juveniles apparently are pelagic, gradually settling on the bottom by the end of April. While in the estuary, young fish eat amphipods and copepods (Moyle 2002).

The Bay Study Otter Trawl is the best monitoring survey for detecting starry flounder, because the Otter Trawl monitors the bottom of the water column. The Otter Trawl indicates that starry flounder exhibit periods of dramatic variation in abundance in San Francisco Bay (see Figure 14), which may be cyclical – although anomalies in survey returns that result from gear-related sampling phenomena may affect returns.

5.3 Environmental Factors Affecting Starry Flounder

Starry flounder spend little of their lives in the estuary. Since their diet while in the estuary consists of amphipods and copepods, reductions in the abundance of these food resources could reduce numbers there. The damage already done to the ecosystem's food web by the invasive Amur River clam is well documented (see, e.g., Carlton et al. 1990; Alpine and Cloern 1992; Kimmerer et al. 1994; Feyrer et al. 2003; Kimmerer 2006; Greene et al 2011). Kimmerer et al. (1994) reported a 69 percent drop in chlorophyll concentration after the Amur River clam became abundant. Greene et al. (2011) found that *P. amurensis* feeds heavily on microzooplankton (e.g., ciliates), which are a food resource for macrozooplankton (e.g., copepods). As a result, the Amur River clam may disrupt links between these trophic levels (Greene et al. 2011).

In the 1980s, increasing anthropogenic discharges of nitrogen were coupled with reductions in phosphorus loading in the estuary (Van Nieuwenhuyse 2007; Glibert et al. 2011). Changes in nutrient forms and ratios caused stoichiometric changes in lower trophic levels, away from a diatom-based food web and toward a less efficient bacterial food web (Glibert 2010; Glibert et al. 2011). According to Glibert (2010), the decline in diatoms, which began in 1982, is highly correlated with the increase in ammonium loading. Diatoms prefer and, under some conditions, physiologically require, nitrate over ammonium. As nitrate became less available relative to ammonium in Suisun Bay, a competitive advantage

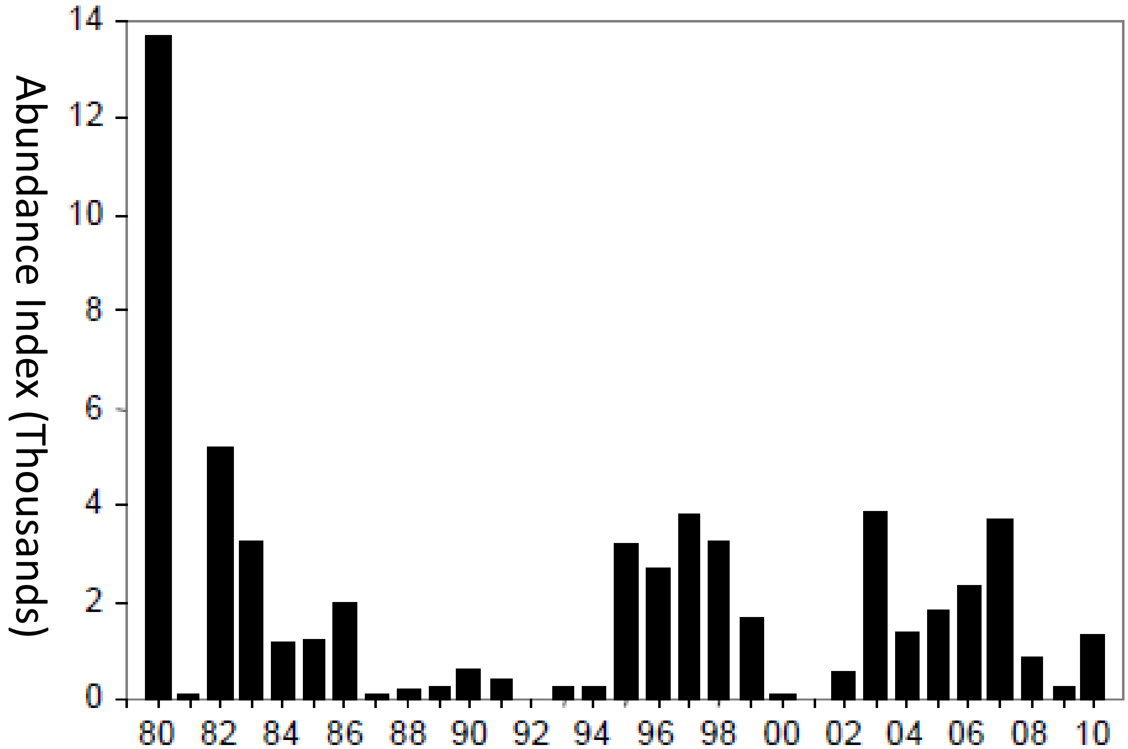

Figure 14. Annual abundance of age-0 starry flounder. Data from Bay Study Otter Trawl. Figure from *IEP Newsletter*, 2012(1), p. 24. Starry flounder appear to undergo cyclic abundances.

shifted to phytoplankton taxa that can more efficiently use reduced forms of nitrogen (Berg et al. 2001; Glibert et al. 2004, 2006; Brown 2009). Among the phytoplankton groups that replaced diatoms in the estuary, cyanobacteria and many flagellates, phytoplankton groups that do not support key food web linkages, show a preference for chemically reduced forms of nitrogen. Today the Suisun Bay region is dominated by cyanobacteria and flagellates (Brown 2009). These changes in phytoplankton composition are consistent with ecological stoichiometric principles, which predict that consumers that successfully sequester the nutrient in lowest supply relative to their needs should dominate and, in so doing, may stabilize at a new stable state (Glibert et al. 2011).

Combined, the effect on the estuary's food web has been severe – its carrying capacity has been reduced as the effects of an altered lower food web have cascaded upward (Kimmerer et al. 2000). Importantly, flows apparently do not alter estuarine nutrient ratios; accordingly, Glibert (2010) states that the current strategy of salinity management will likely show little beneficial effect on phytoplankton, zooplankton, or fish. Rather, regulation of effluent nitrogen discharge through nitrification and denitrification offers an alternative management strategy with a track record of success in other estuaries (see the PWA presentation on ecosystem changes and the low-salinity zone, *Ecosystem Changes to the Bay-Delta Estuary: A Technical Assessment of Available Scientific Information,* pp. 2-23 to 2-39).

6.0 American Shad

6.1 Introduction and Summary

American shad is not an estuarine species. It spawns and rears to adulthood in areas above the estuary in the open waters of larger rivers (Moyle 2002). Variation in population numbers drawn from the Fall Midwater Trawl index indicates that through-Delta flows do not determine American shad population dynamics.

6.2 American Shad Biology

The American shad, *Alosa sapidissima,* is an anadromous fish that was intentionally introduced into California in the late 1880s. They are found along the Atlantic seaboard from Labrador to Florida and are one of the most abundant anadromous fish on the east coast. Since its introduction in California, it has become an important sport fish in the San Francisco estuary. American shad range from Alaska to Mexico and use major rivers between British Columbia and the Sacramento-San Joaquin watershed for spawning (Moyle 2002).

At age-3 to age-5, American shad migrate from the ocean into freshwater reaches of the Sacramento and San Joaquin rivers during March-May, with peak migration occurring in May (Stevens et al. 1987). American shad spawn in open waters and do not often move up into the lesser tributaries of the large rivers that they ascend. The major spawning run in California occurs in the Sacramento River up to Red Bluff and in the adjoining American, Feather, and Yuba rivers, with lesser use of the Mokelumne, Cosumnes, and Stanislaus rivers and the Delta (Moyle 2002). Spawning takes place from May-July (Stevens et al. 1987). American shad are not semalparous (spawn only once and then die) like salmon; they will return annually up to seven years of age to spawn (Stevens et al. 1987), although the majority of spawners are first-time participants (Moyle et al. 2002). The young migrate seaward through the estuary from June through December (Stevens 1966). It is hypothesized that river flows affect the distribution of first time spawners, with numbers of newly mature adults spawning in rivers proportional to flows at the time of arrival (Stevens et al. 1987), with spawning taking place in the main channels of the rivers and flows washing negatively buoyant eggs downstream.

The lower Feather River and the Sacramento River from Colusa to the northern estuary provide the major summer nursery areas for larvae and juveniles, although there is some evidence that at least some American shad spawn in the estuary itself (Stevens 1966) – note that American shad juveniles can tolerate an abrupt switch to sea water (Moyle 2002).

Flows are hypothesized to affect the downstream transport of young, with wet years moving the location of the concentration of young and their nursery area further downstream (Stevens et al. 1987); however, it is unclear how enhanced flows provide benefits to the American shad population. Out migration of young American shad through the estuary occurs June-November (Stevens 1966). During migration to the ocean, young fish feed upon zooplankton, including copepods, mysids, and cladocerans, as well as amphipods (Stevens 1966; Moyle 2002). Most American shad migrate to the ocean by the end of their first year, but some remain in the estuary (Stevens et al. 1987; Moyle 2002).

Year-class strength correlates positively with river flow during the April-June spawning and nursery period (Stevens and Miller 1983.) Age-0 American shad exhibit a weak abundance relationship with the location of the X2 isohaline in the estuary (Kimmerer 2002). After 1987, the relationship changed such that abundance increased per unit flow (Kimmerer 2002; Kimmerer 2009); the X2 location versus abundance relationship has remained intact in recent years (Kimmerer et al. 2009.) In addition, Kimmerer et al. (2009) found that American shad exhibit a relationship with salinity and water depth that appeared consistent with its relationship of abundance to X2 location; that is, slopes for abundance versus X2 and salinity and depth versus X2 are similar, which provides some support for the idea that increasing the extent of areas of specific salinity and depth could explain the X2-abundance relationship for the species. Stevens and Miller (1983) hypothesized that the apparent general effect of high flow on all of the species they examined, including American shad, is to increase the extent and quality of nursery areas, thereby more widely dispersing young fish, thus reducing density-dependent mortality.

6.3 Environmental Factors Affecting American Shad

An examination of the annual abundance index for American shad indicates the population's fresh water residency undergoes wide swings, with nearly biennial peaks and troughs (Figure 15). As shown by Figure 15, low index values experienced from 2007-2011 are not unusually low when compared to early to mid-1970s returns. For water flows to produce such an effect, alternating extreme events producing boom-or-bust conditions would have to occur. Such has not been the case. More likely, cycling numbers of American shad may be an artifact of the timing of American shad's movements through the estuary in relation to the Fall Midwater Trawl. Stevens and Miller (1983) acknowledged that the Fall Midwater Trawl index is affected by imprecision in data derived from generalized sampling techniques that are not designed to accommodate species-specific ecological phenomena.

While Kimmerer et al. (2009) found that American shad exhibit an abundance relationship with X2 location in the Delta, the relationship is weak, which indicates little support for the idea that increasing habitat by moving X2 downstream will benefit American shad. Stevens and Miller (1983) suggest that American shad abundance is affected by estuary inflows. That is consistent with Moyle (2002), who reported that shad are able to adjust the timing of their spawning runs to the timing of river outflows. The biennial nature of the Fall Midwater Trawl abundance index for American shad belies a substantive influence of flows and instead suggests that American shad, as a long-lived species, can choose their spawning years to correspond with wet years.

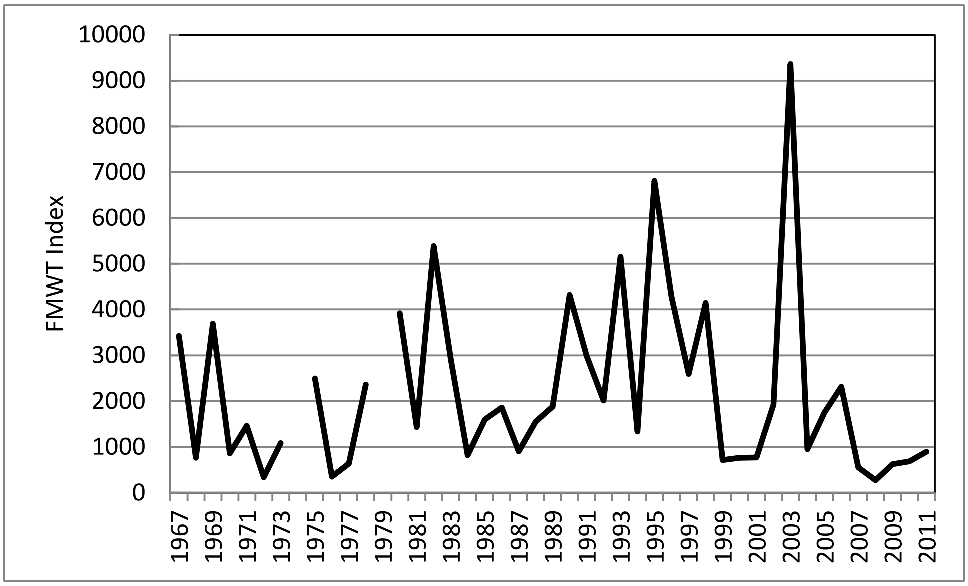

Figure 15. Annual index of American shad abundance. Data from Fall Midwater Trawl.

7.0 Northern Anchovy

7.1 Introduction and Summary

The northern anchovy is abundant off the coast of California and is ecologically and economically important in the coastal waters of southern California. Three stocks of northern anchovy have been identified -- northern, central and southern. California fishery harvests are taken from the central stock, which ranges from northern Baja to San Francisco. Management of northern anchovy is shared by the Pacific Fishery Management Council and the National Marine Fisheries Service. Data do not indicate that the northern anchovy is experiencing a decline.

7.2 Northern Anchovy Biology

In the winter, northern anchovy, *Engraulis mordax*, usually move to deeper water offshore, and in the spring they return to inshore shallow waters. Spawning is mostly within 60 miles of the coast, although it has been recorded up to 300 miles offshore. Anchovies stay near the bottom in the daytime and come to the surface at night. They spawn mostly in the ocean at depths less than 10 meters, at water temperatures of 12-15^{o}C (Kucas 1986). Anchovies spawn throughout the year, although most spawn in winter and spring (Kucas 1986). While the northern anchovy diet consists of zooplankton, phytoplankton, and fish, it is primarily a planktivore (Kucas 1986; Kimmerer 2006).

7.3 Environmental Factors Affecting Northern Anchovy

The response of northern anchovy to changed conditions in the estuary is noteworthy; its recent shift in distribution appears to have been a direct behavioral response to reduced food. Prior to invasion by the Amur River clam, summer-long phytoplankton blooms were common. In 1987, the clam eliminated these blooms, leading to a redistribution of northern anchovy toward higher salinity, reducing its summer abundance in the low-salinity zone by 94% (Kimmerer 2006).

The decline in anchovies in the estuary's low-salinity zone, but not in areas of higher salinity, occurred in striking coincidence with the decline in chlorophyll-*a*. The bulk of the northern anchovy population, before the recent decline was documented, occurred at high salinity – 95% of the catch before 1987 occurred at >10 psu salinity (Kimmerer 2006). Hence, their declines in the low-salinity zone most likely occurred directly in response to declines in food availability, since there has been no long-term change in the distribution of the low-salinity zone within the estuary in the spring. Furthermore, chlorophyll-*a* concentrations did not change appreciably in San Pablo Bay (Kimmerer 2004), a higher-salinity region where anchovy abundances have remained high.

Kimmerer (2006) explored several possible explanations for the dramatic and rapid decline in northern anchovy in the low-salinity zone in 1987 and thereafter, including climate variability and biomass, catch, or abundance of northern anchovy on the California coast, and concluded that the most parsimonious explanation for the decline in anchovy abundance in the low-salinity zone is as a direct or indirect response to the decline in chlorophyll-*a*.

The shift of the population away from a region that had become inhospitable is not surprising. In the lower Hudson River, several open-water fish species shifted seaward following a reduction in chlorophyll concentration due to the introduced zebra mussel *Dreissena polymorpha* (Strayer et al. 2004 in Kimmerer 2006). Similar behavioral shifts of northern anchovy in apparent response to chlorophyll concentration (or its covariates) have been noted off Baja California (Robinson 2004 in Kimmerer 2006). Behavioral shifts in the geographic position of populations in response to food availability is a simpler explanation for observed phenomena that recognizes the ability of animals to move from unfavorable to favorable locations.

8.0 Striped Bass

8.1 Introduction and Summary

Striped bass are a non-native species.

8.2 Striped Bass Biology

Striped bass, *Morone saxatilis*, were deliberately introduced in California from the East Coast, where they are found from the Gulf of St. Lawrence to Alabama. The initial introduction took place in 1879, when 132 fingerling bass were brought to California by rail from the Navesink River in New Jersey and released near Martinez. Fish from this lot were caught within a year near Sausalito, Alameda, and Monterey, and others were caught occasionally at scattered locations for several years afterwards. There was much concern by the Fish and Game Commission that such a small number of bass might fail to establish the species, so a second introduction of about 300 striped bass was made into lower Suisun Bay in 1882.

In a few years, striped bass were being caught in California in large numbers. By 1889, only a decade after the first lot of eastern fish had been released, bass were being commercially harvested and sold in San Francisco markets. In another decade, the commercial net catch was averaging well over a million pounds a year. In the belief that it would enhance the sport fishery, in 1935 the Fish and Game Commission declared striped bass to be a game fish and all commercial fishing for striped bass was halted.

Striped bass have been monitored more extensively than perhaps any other Bay-Delta fish. The Fall Midwater Trawl was designed to determine the relative abundance and distribution of age-0 striped bass in the estuary. It has sampled portions of the estuary annually since 1967 (with the exceptions of 1974 and 1979). Currently, it samples 122 stations each month from September to December, and a subset of these data is used to calculate an annual abundance index. The 122 stations range from San Pablo Bay upstream to Stockton on the San Joaquin River, Hood on the Sacramento River, and the Sacramento Deep Water Ship Channel in the upper estuary. Oblique tows from bottom to top are conducted at each of the stations.

8.3 Environmental Factors Affecting Striped Bass

The FMWT Index for age-0 striped bass shows a dramatic and persistent decline starting in 1987 (Figure 16). Bioenergetic modeling provides evidence that major changes to the estuarine food web are primarily responsible for the decline (Nobriga 2009). Kimmerer et al. (2000) also suggests a decline in the estuary's carrying capacity due to food limitation. Feyrer et al. (2003) noted a major decline in mysid abundance caused by the invasion of the Amur River clam as a cause of the decline in striped bass abundance and a switch to piscivory by earlier age classes. Bryant and Arnold (2007) suggest the most significant impact of food limitation occurs during first-feeding by larvae in the spring, since Summer

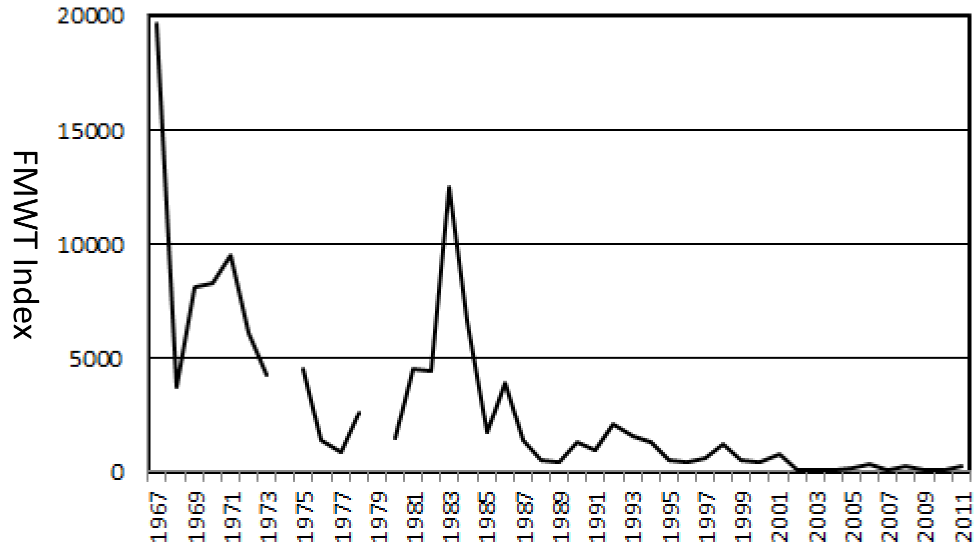

Figure 16. Fall Midwater Trawl index for striped bass.

Townet Survey data indicates that striped bass diets have adjusted to changes in the summer food availability.

At least part of the decline in age-0 striped bass abundance can be explained by an apparent long-term distributional shift away from channels, which are sampled by the FMWT, toward shoal areas, which are not (Schroeter 2008; Sommer et al. 2011). Therefore, at least part of the decline in the FMWT Index is attributed to under-sampling of striped bass habitat. Reduced food availability in pelagic habitat caused by the invasion of the Amur River clam is hypothesized by Sommer et al. (2011) to be the major cause of the distributional shift. Glibert et al. (2011) found that both ammonium levels and nutrient ratios explained the variation in age-0 striped bass abundance as measured by the FMWT.

A decline in the number of age-0 striped bass would manifest itself as reduced recruitment (Kolhorst 1999), but the overall population of adult striped bass has not shown a decline since 1987 (Figure 17), nor has the population of sub-adult fish (Figure 18). Striped bass have a wide-ranging diet, consuming copepods, planktonic crustaceans (e.g., *Daphnia* spp.), cladocerans, mysids, amphipods, small fishes, and other prey (Bryant and Arnold 2007). Only age-0 fish have a more constrained diet (they are non-piscivorous at smaller sizes). The fact that neither sub-adult nor adult striped bass numbers have declined over decades suggests that the number of age-0 fish recruiting to the adult population is sufficient to ensure a robust and apparently sustaining population. Recreational catches of striped bass also have not declined from the early 1980s (see Figure 17). An apparent surge in recreational catch happened in the late 1990s, but without a subsequent pattern.

Kimmerer (2002) found that survival of striped bass from eggs to 38 mm is increased as the location of the X2 isohaline shifts downstream in the estuary. Given that age-1 through age-6 fish have not experienced overall declines in numbers, little is gained from a population perspective by shifting X2 downstream. Density dependence offers an explanatory mechanism whereby the number of age-0 striped bass is delinked from the

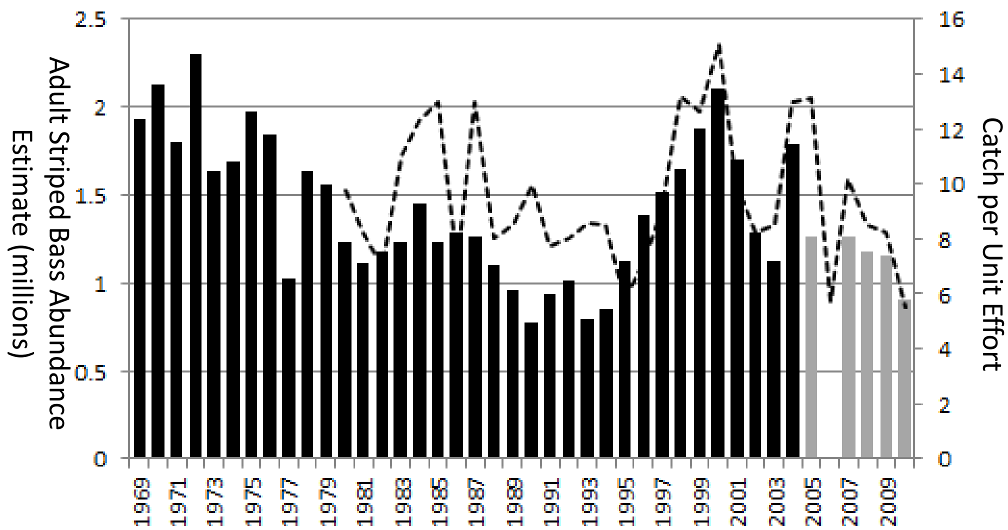

Figure 17. Population abundance estimates of adult striped bass (age-3 to age-6). Data from Loboschefsky et al. (2012) 1969-2004; 2005-2010 (gray bars) estimated using the same methods as Loboschefsky et al. 2012. Catch per unit effort (dashed line) from California Department of Fish and Game, http://nrm.dfg.ca.gov/documents/ContextDocs.aspx?cat=R3-StripedBassStudy.

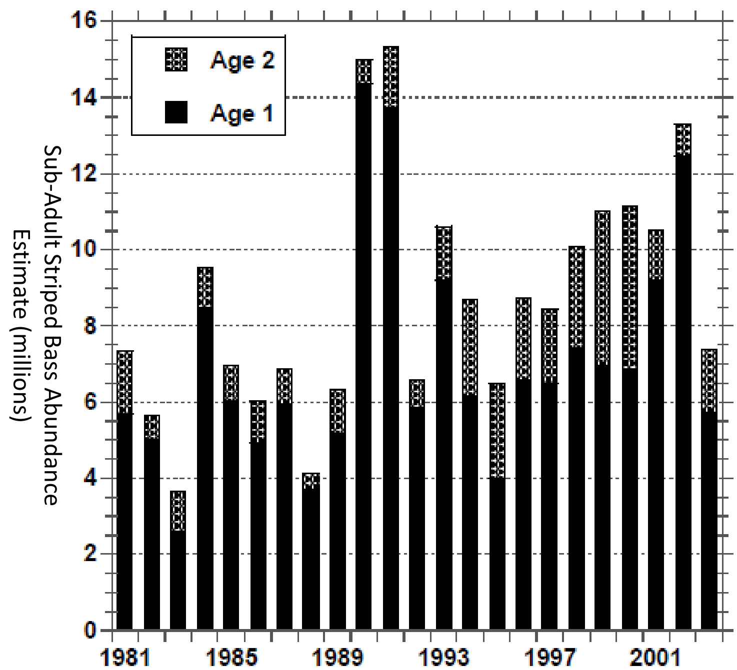

Figure 18. Population abundance estimates of sub-adult striped bass (age-1 and age-2). From Loboschefsky et al. (2012) Figure 3.

number of older fish. Kimmerer et al. (2000) found a density-dependent survival bottleneck during the first three to four months of life, and offered as reasonable candidates for causation density dependence, food limitation, cannibalism, response of predators, and migration. The study identified food limitation as the most likely candidate.

Contaminants may also explain some of the decline in striped bass abundance. Ostrach et al. (2008) examined maternal transfer of contaminants in striped bass and reported: "*The results from this study clearly demonstrate that xenobiotics are adversely affecting early-life-stage striped bass in the San Francisco Estuary and need to be considered as one of multiple stressors affecting the continuing population decline*." Ostrach et al. (2008) further concluded: "*Our results indicate that pesticides not in use for decades, such as DDT and its degradation products, are still persistent in the estuary and are being made bioavailable by recycling through the food chain to apex predators. Furthermore, our results show that these contaminants are being transferred to their progeny in biologically relevant levels.*"

Further analysis found results consistent with the earlier studies (Ostrach et al. 2009). In addition, Sommer (2008) reported that the sex ratio of young of the year striped bass in the Delta is heavily skewed toward male (90:10 male:female). While the cause of this skewed sex ratio is unknown at this time, exposure to endocrine disrupting chemicals cannot be ruled out.

9.0 California Bay Shrimp

9.1 Introduction and Summary

A relationship between the location of the X2 isohaline in the estuary and California bay shrimp abundance has continued without change after invasion of the Amur River clam in 1986 (Kimmerer et al. 2009). No known mechanism of effect has been identified for how California bay shrimp respond to estuarine flows, but it is hypothesized to be increased passive upstream transport of juvenile shrimp by strong bottom currents due to gravitational circulation (Siegfried 1989; Moyle 2002).

Glibert et al. (2011) found that bay shrimp abundance, as measured by the FMWT, was related to nutrients as well as to the location of X2, leading to uncertainty as to whether salinity (a proxy for through-Delta flow) or nutrients are the controlling variable.

9.2 California Bay Shrimp Biology

California bay shrimp, *Crangon franciscorum*, occurs in coastal bays along the Pacific Coast of North America from southeastern Alaska to at least San Diego, CA (Wang 1986). Two other closely related shrimp also exist in the Bay-Delta, the black shrimp *Crangon nigricauda* and the blue-spotted shrimp *Crangon nigromaculata*. Both of these prefer higher salinity water and are not associated with the eastern reach of the estuary and the Delta. Adult California bay shrimp feed on bay bottoms on crustaceans, polychaetes, mollusks, foraminiferans, and plant material. Amphipods are the most frequently ingested (Wang 1986; Siegfried 1989). *Crangon* shrimp live for approximately two years. They are an important food resource of the principal sport and commercial fisheries of Pacific Coast estuaries (Wang 1986). A bait fishery accounts for a small annual harvest.

Bay shrimp spawn in bay waters and may spawn multiple times (Wang 1986). The larvae are initially found in near-surface waters of the bay, while later stage larvae are associated with the bottom of the water column. This places them in favorable position for dispersal up-estuary by gravitational circulation. Their abundance commonly peaks in spring and summer in low-salinity waters (Wang 1986). As the juveniles mature, they move to higher salinity waters. By fall the late-juveniles move back out into bay waters, apparently related to reproduction. Annual abundance of bay shrimp has been linked to the volume of through flows to San Francisco Bay (Wang 1986; Kimmerer et al. 2009).

The distribution of the opossum shrimp is associated with the distribution of bay shrimp in the estuary; its density is greater in locations where mysids are abundant (Siegfried 1980). The abundances of early and mid-stage bay shrimp larvae in the estuary – the only stages using the upper estuary – are negatively correlated with estuary through flow (Kimmerer et al. 2009). In years of high freshwater outflow, a larger proportion of the reproductive population moves from bays to the near-shore coastal area, resulting in more larvae hatched outside the bays (Siegfried 1986), but with no apparent reduction in overall population size(s) as a result of diminished flows.

9.3 Environmental Factors Affecting California Bay Shrimp

Organochlorine pesticide toxicity to bay shrimp has been reported (Wang 1986 and references therein). Its lethal threshold was estimated to be 100 ppb, while sub-lethal effects include increased physical activity, and decreased feeding and molting rates (Wang 1986).

The relationship between bay shrimp and the opossum shrimp (*N. mercedis*) suggests a more important effect. The effect of the invasive Amur River clam on *N. mercedis* abundance is well documented in the literature; Glibert et al. (2011) found that nutrient forms and ratios predicted *N. mercedis* abundances better than the location of X2 in the estaury (Figure 19). Flows do not alter the nutrient ratios. Glibert (2010) points out that the current strategy of salinity management will likely show little beneficial effect on phytoplankton, zooplankton, or fish. Rather, regulation of effluent nitrogen discharge through nitrification and denitrification offers an alternative management strategy with a history of success in other estuaries (see PWA submittal *Ecosystem Changes to the Bay-Delta Estuary: A Technical Assessment of Available Scientific Information,* pp. 2-28 to 2-39).

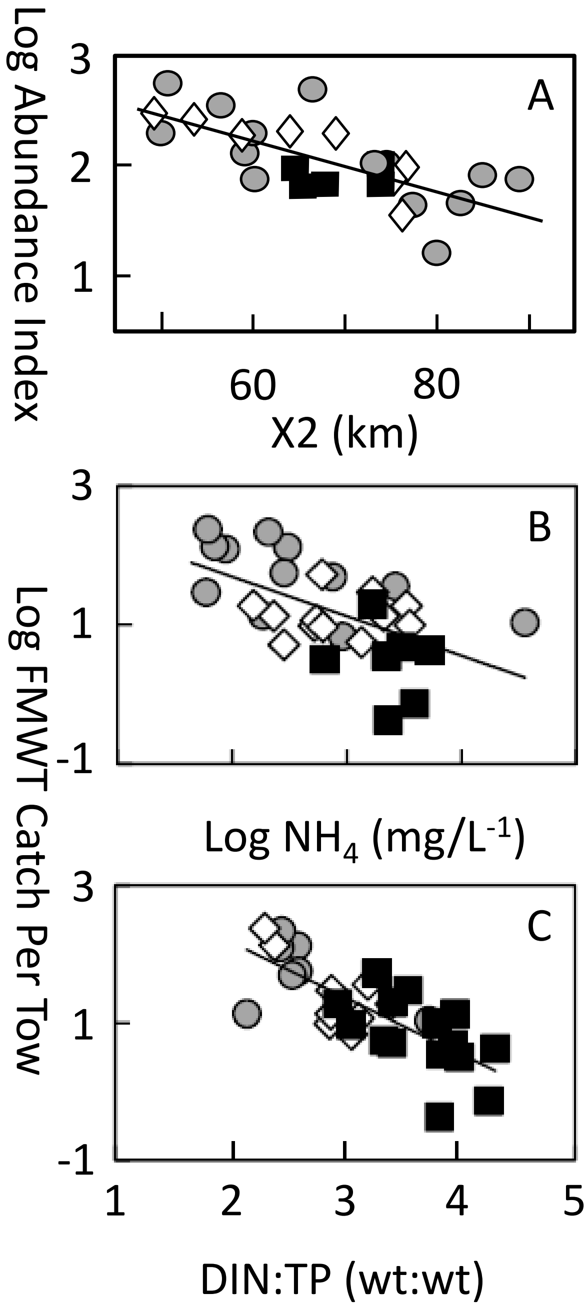

Figure 19. Change in abundance of California bay shrimp over time in relation to (A) spring X2 location, (B) ammonium, (C) nitrogen:phosphorus ratio. Abundance data is log transformed. 1975-1986 (circles); 1987-1999 (diamonds); post-1999 (squares). (A) from Kimmerer et al. (2009) Figure 3; (B) and (C) from Glibert et al. (2011) Figure 16.

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BAY-DELTA FISHERIES RESOURCES: Review of the Available Scientific Information Regarding Salmonids

September 14, 2012

Submitted by: State Water Contractors, Inc.
San Luis & Delta-Mendota Water Authority

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Acronyms

BA	Biological Assessment
BDCP	Bay Delta Conservation Plan
BiOp	biological opinion
CDFG	California Department of Fish and Game
cfs	cubic foot/feet per second
Chl *a*	Chlorophyll *a*
cm	centimeter
CPUE	catch per unit effort
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CWT	coded wired tag
D-1641	1995 Bay-Delta Water Quality Control Plan

DPM	Delta Passage Model
DPS	distinct population segment
DWR	California Department of Water Resources
E:I	Export to Inflow
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FERC	Federal Energy Regulatory Commission
HORB	Head of Old River
IOS	Interactive Object-oriented Simulation
JPE	juvenile production estimate
JSATS	Juvenile Salmon Acoustic Telemetry System
km	kilometer
MAF	million acre-feet
µg L-1	microgram(s) per liter
mm	millimeter
OBAN	Oncorhynchus Bayesian Analysis
OCAP	Operational Criteria and Plan
OMR	Old and Middle Rivers
PFMC	Pacific Fisheries Management Council
POC	particulate organic carbon
PTM	Particle Tracking Model
RBDD	Red Bluff Diversion Dam
RPA	Reasonable and Prudent Alternatives
SAV	submerged aquatic vegetation
SI	Sacramento Index
SJRA	The San Joaquin River Agreement
SLDMWA	San Luis & Delta-Mendota Water Authority
SRTTG	Sacramento River Temperature Task Group
SWC	State Water Contractors
SWRCB	State Water Resources Control Board
SWP	State Water Project
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VAMP	Vernalis Adaptive Management Plan

ES EXECUTIVE SUMMARY

ES1. Introduction

In several scheduled workshops, the State Water Resources Control Board (State Water Board) will receive information regarding the scientific and technical basis for potential changes to the 2006 Water Quality Control Plan for the Bay-Delta. The following materials related to salmonid species within the Sacramento-San Joaquin Rivers/Bay-Delta Estuary have been prepared by the State Water Contractors (SWC) and the San Luis & Delta-Mendota Water Authority (SLDMWA) to help inform the workshop on Bay-Delta Fishery Resources.

The SWC and SLDMWA have compiled and assessed available scientific information on fishery resources in the Bay-Delta estuary and summarized that information in two papers, one on Pelagic Fish (submitted separately), and this paper, on salmonid species within the Bay-Delta estuary and Central Valley watersheds of the Sacramento and San Joaquin Rivers.

The best available information shows that multiple interacting variables affect Central Valley salmonid population dynamics. While uncertainty remains regarding which stressors, if any, may be the primary drivers of species abundance, the most recent data suggest that predation throughout the watershed, as well as upstream habitat and ocean conditions are among the most important factors.

The considerable physical changes that have occurred since settlement, including construction of rim dams, channelization of Delta waterways, and eliminating access to floodplains, wetlands and other habitats, have significantly and detrimentally affected salmonids. The complex estuarial problems that have resulted cannot be rectified through additional releases from reservoirs or increased outflow from the Delta. Focus should also be placed on restoring functions necessary to restore salmon abundance.

And, overemphasizing flow regimes as a restoration mechanism for protecting salmonids is unlikely to provide meaningful, long-term benefits to the species and may do more harm than good. As a primary example, one of the most critical factors in winter-run and spring-run Chinook salmon abundance is careful coldwater pool management during the spawning and upstream juvenile rearing periods. Requiring additional reservoir releases could deplete coldwater reserves for use in later months and later years to such an extent that winter-run and spring-run Chinook salmon's risk of extinction could be increased.

ES2. Findings

Results from a substantial body of scientific research in the past two decades and more recent lifecycle modeling have collectively provided a robust picture of the behavior and needs of Central Valley salmonids. The scientific literature shows that increasing the abundance and distribution of Central Valley salmonids requires considering all the stressors on salmonid species. Continued or increased management of water projects without addressing other direct and indirect stressors will not reduce threats to species' survival and recovery and may contribute to further declines in salmonid species.

Specific findings detailed in this report include the following:

- Upstream conditions (including water temperature and suitability of spawning habitat), predation, and ocean conditions (for rearing and ocean harvest) are significant drivers of survival and abundance for fall-run, late fall-run, winter-run, and spring-run Chinook salmon.

- Salmonids spend most of their lifecycles upstream of the Delta and in the ocean. Most salmonids spend 2% to 9% of their lifecycles (between 1 week to 3 months) in the Delta;
- There is a weak positive relationship between river flow and survival of juvenile Chinook salmon and Central Valley steelhead. Existing flows would have to be substantially increased to provide even modest improvement in juvenile migration survival to and through the Delta and even such modest improvements are uncertain in the absence of improvements to adjacent habitat conditions;
- Maintaining adequate upstream coldwater pool volumes is critically important to salmonid reproduction and abundance. Increased reservoir releases to augment Delta inflows or outflows could adversely impact cold water pool management in the summer and fall and the long-term viability of some salmonid species;
- Additional Delta inflows or outflows will have no effect on ocean conditions, which appears be a major determinant of salmonid abundance;
- Tidal flows overwhelm (i.e., are approximately 10 times larger than net Delta outflow) in the western Delta. Thus, even doubling Delta outflows will not significantly affect juvenile salmonid migration rates through the Delta.

ES3. Salmonid Lifecycles

The reproductive success, survival, growth, and overall abundance of Central Valley salmonids are impacted by a wide variety of factors, including flows, water temperature, availability and habitat suitability for spawning and rearing, seasonal inundation of floodplains, predation, and recreational and commercial fishing practices. As a result, the length of individual life stages and species abundance varies between species, rivers and years.

Central Valley Rivers support four Chinook salmon species: winter-run, spring-run, fall-run, and late fall-run, as well as steelhead. These species are anadromous fish that spawn in freshwater but rear for most of their lifecycles in coastal ocean waters. Chinook salmon and steelhead migrate upstream from the ocean, through the Delta, and into Central Valley Rivers during the fall, winter, and spring months depending on species (and the name for Chinook salmon, such as winter-run, reflects the seasonal timing of adult upstream migration). For some species, rearing occurs in upstream areas followed by a downstream migration as smolts (physiologically capable of the transition from freshwater to saltwater), while other species migrate downstream shortly after emergence to rear in the lower reaches of the rivers or the Bay-Delta until ready to move into saltwater. Salmonids are generally distributed throughout the Central Valley, except for Winter-run Chinook which spawn and rear only in the mainstem of the Sacramento River.

The timing of some salmonid lifecycle stages varies between species. For example, after emergence, rearing in upstream river reaches varies from 4 to 42 weeks for Chinook species and between one to two years for steelhead. Late Fall-run Chinook and Steelhead only use the Delta as a migration corridor for 1 to 2 weeks, but Fall-run Chinook, Spring- run Chinook, and Winter-run Chinook may spend between 2 and 12 weeks within the Bay-Delta before migrating to the ocean. Because salmonids typically have a 3 year lifespan, the time they spend in the Delta varies between 2 and 9 percent of their lifespan.

Although flow is often suggested as a predictor of salmonid abundance (with high flows one year resulting in increased upstream adult migration in subsequent years), the relationship between flow and abundance is characterized by high variability. Higher instream flows during the late winter and spring months (even in sequential years) may or may not result in increased salmonid survival and abundance. Because land-based factors that affect salmonid survival and abundance have been studied for several decades, ocean conditions (including food abundance) is often suggested as an important (and little understood) determinant of salmonid abundance.

ES4. Regulatory and Habitat Enhancement Programs

A number of regulatory requirements have been implemented to enhance and protect critical and essential habitat for Central Valley Chinook salmon, steelhead, and other aquatic resources within the Bay-Delta estuary and Central Valley Rivers and tributaries. Although these programs have improved fish abundance in some locations and seasons, variability in salmonid abundance remains.

These regulations include actions by the State Water Resources Control Board, Central Valley and San Francisco Bay Regional Water Quality Control Boards, National Marine Fisheries Service (NMFS), Central Valley Project Improvement Act (CVPIA), California Department of Fish and Game (CDFG) agreements, Federal Energy Regulatory Commission (FERC) actions, and Pacific Fisheries Management Council (PFMC) decisions, such as ocean harvest restrictions.

In addition, over the past decade a number of habitat improvement and enhancement projects have been designed and implemented as part of programs such as CALFED and the CVPIA Anadromous Fish Improvement Program. These programs have resulted in spawning gravel augmentation and habitat restoration, reduced risk of entrainment mortality through installation of fish screens on previously unscreened water diversions, and installed new fish ladders to improve access to upstream habitat. Additional beneficial actions include improved access to seasonally inundated floodplains, channel margin habitat, tidal wetlands, hatchery management, harvest regulations and other actions to reduce stressors on salmonids. The Data Assessment Team and salmon decision tree management process have also helped improve conditions for salmonids. However, even with these measures, salmonid abundance continues to vary.

ES5. Analytical Tools and Lifecycle Models

Results of recent lifecycle modeling suggest that upstream conditions, ocean conditions for rearing and ocean harvest, and predation primarily drive salmon survival and abundance.

Several analytical tools have been developed to provide a framework to identify and evaluate potential management actions, assess the relative importance of individual stressors on overall population dynamics, and allow comparative cost/benefit assessments. However, many of these tools were developed to address specific management actions, life stages, or addressed only a limited geographic area.

Recent lifecycle models more accurately reflect differences in life stages, geographic distribution, and factors that influence spawning, growth, survival, and abundance. Lifecycle models provide a tool for assessing the relative importance of various factors on the abundance of adults as reflected by the beneficial or adverse effects of stressors at each life stage. These models provide an analytical framework for application of the best available scientific information regarding the response of a given life stage to a management action or environmental condition. Lifecycle models can also help identify future monitoring or research that could improve model assumptions and better identify functional relationships.

ES6. Linkages between Flow and Salmonid Survival

There is a weak positive relationship between river flow rate and juvenile salmonid survival. The scientific literature suggests that enormous changes in flow are necessary to achieve even a small change in survival in the Sacramento and San Joaquin rivers and even such modest

improvement is uncertain. Increasing flows through reservoir releases or reduced diversions will not restore many of the functions that Central Valley rivers and the Delta provided in the past. Elevated water temperatures and predation are important factors that substantially impact salmonid survival and changes in reservoir operations or rates of diversion will not resolve these issues. Tidal hydrodynamics will overwhelm any perceived benefits of changes in reservoir operations or rates of diversion for juvenile salmonid migration in the Delta.

ES6.1 Biological Roles of River Flows

River flows and associated olfactory parameters serve as environmental cues for adult salmonid attraction and upstream migration to spawning habitat. Instream flows are needed to provide sufficient water depths for adult upstream passage and adult holding in the upper reaches of rivers prior to spawning. River flows also help to regulate water temperatures, increase dissolved oxygen levels, flush fine sediments that deposit on gravels used for spawning, and remove metabolic waste from incubating salmonid eggs. Flows also transport macroinvertebrates and zooplankton from upstream areas to rearing juveniles. Pulse flows in the winter and spring, increase turbidity, and seasonal increases in water temperature provide cues for downstream migration of juvenile salmonids.

ES6.2 Use of Flows to Regulate Water Temperature

Dam and levee construction, loss of wetlands, and reduced floodplain inundation within the Central Valley have limited the geographic distribution of salmonids and reduced species abundance. Various projects and programs have been implemented to address these adverse effects, including reservoir coldwater pool management and timed flow releases to maintain suitable water temperatures below those reservoirs. Because water in river channels is exposed to ambient air and solar radiation, water temperatures increase as a function of distance downstream of a dam until a thermal equilibrium is reached. Thus, while in spring, summer and fall, coldwater pool releases can reduce instream water temperatures in limited river reaches below dams, for most of the Sacramento River and all of the Delta such releases have no effect on instream water temperatures.

Flow augmentations have been suggested as a tool to increase abundance of desired fish species in the Bay-Delta estuary. Modeling of the potential impact of increased reservoir releases suggest that reservoir storage and thus available cold water at Shasta, Oroville, Trinity and Folsom Reservoirs would be substantially impacted by winter and spring releases (between November and June).

Reservoirs that reach dead pool—particularly in consecutive years—would expose downstream salmonids to stress and mortality from elevated water temperatures, reduce instream flow and physical habitat, and could reduce population abundance and increase risk of species extinction. Adverse impacts would also be likely for coldwater resident fish such as rainbow trout downstream as well as fish populations within the reservoirs. If ambient air temperatures increase in the future due to climate change, water temperatures would also increase, and the severity of adverse effects to salmonids and other fish species from coldwater pool depletion would likely increase.

ES6.3 Relationship between Flow and Survival

Numerous studies have been conducted in the Sacramento and San Joaquin river systems and in the Delta in the past 25 years to examine the relationship between flow and salmonid survival, and how changes in river flows affect migratory processes for juvenile salmonids. In general, studies have also shown high total mortality (70 to 80%) for juvenile salmon migrating downstream in the Sacramento River before they reach the northern Delta.

Survival studies have identified a positive trend of increased juvenile survival during migration when river flows are higher. However, these studies show: 1) high variability in juvenile survival for a given flow; 2) a weak relationship between survival and flow, which indicates that flow does not explain a substantial proportion of the observed variation in survival; and 3) a substantial increase in flow would be required to achieve a small increase in predicted salmonid survival.

Tidal flows are typically much larger that net Delta inflows. As a result, Delta inflows and outflows are likely to be overwhelmed by tidal hydrodynamics.

ES7. Salmonids in the Sacramento River System

Despite the construction of dams on the river and most major tributaries, analyses of Sacramento River hydrology indicate that the system continues to be characterized by winter and spring pulse flows from storm events that increase turbidity and contribute to migration cues for juvenile salmonids. Producing pulse flows through reservoir releases will not increase turbidity in the system, mimic seasonal increases in water temperatures, directly affect fish size, or improve and migration cues.

The Sacramento River and its tributaries, including the American, Feather and Yuba rivers, and Battle, Clear, Butte, Deer, Mill and a number of other creeks tributary to the river, support populations of Chinook salmon and steelhead. Access to spawning and rearing habitat for salmonids in the Sacramento River basin has been severely modified due to dam construction, river and stream channelization, levee construction and rip-rapped bank protection, reclamation of tidal wetlands and channel margin habitat, and management of areas for flood control purposes that historically functioned as seasonally inundated floodplain habitat. Water diversions have altered the magnitude and seasonal timing of flows. The introduction of non-native fish and other aquatic species has altered fish community dynamics.

Survival of juvenile Chinook salmon during emigration through the Sacramento River and Delta are positively correlated to fish size (larger juvenile salmon typically have higher survival rates) and Sacramento River flows, but are not significantly related to either the percentage of direct losses as recorded as tag group salvage at the State Water Project (SWP) and Central Valley Project (CVP) export facilities or combined SWP and CVP export rates (indirect effect).

Results of coded wire tag (CWT) survival studies have shown that survival of juvenile salmon migrating downstream through the lower Sacramento River and Delta is highly variable within and among years. Survival rates are weakly correlated with Sacramento River flow and Delta inflow and outflow during the seasonal migration period. In addition, fish size and migration timing can have significant effects on juvenile Chinook salmon survival during emigration.

Studies on downstream migration, using coded wire tag mark-recapture techniques, report higher survival rates for juvenile salmon that migrate in the Sacramento River and lower survival rates for those that migrate into the interior Delta through the Delta Cross-Channel and Georgiana Slough. Recent results from limited acoustic tagging studies have confirmed results of the earlier studies showing higher mortality for salmonids migrating into Georgiana Slough. The performance of a non-physical barrier at Georgiana Slough was tested in 2011 and 2012, and appears to have reduced juvenile salmonid migration into the interior Delta.

Acoustic tagging studies undertaken in the past decade have added substantially to the body of scientific information that can be used in investigating mechanisms and factors that affect juvenile salmon survival. However, until recently, this technology has been limited to relatively large, surgically implanted tags requiring the use of larger (greater than 100mm), hatchery-raised salmon which may not be representative of the survival of smaller salmon fry and smolts during downstream migration. Advancements in acoustic tag technology (allowing use of smaller fish) are continuing and are expected to substantially improve the understanding of juvenile salmonid survival, and address uncertainty from earlier studies.

ES8. Salmonids in the San Joaquin River System

A substantial decline in survival over time not related to river flow or exports has been identified. It has been hypothesized that ocean rearing conditions and increasing abundance of predatory fish in the south Delta may be factors contributing to the trend of declining salmon survival.

The primary San Joaquin River tributaries, the Merced, Tuolumne, and Stanislaus rivers, support spawning and rearing of fall-run Chinook salmon and small populations of steelhead.

The San Joaquin River basin fall-run Chinook salmon population has been characterized by high variability in adult returns to the system that may reflect a cyclical pattern in abundance related to cyclical ocean rearing conditions (e.g., Pacific Decadal Oscillation). In addition, the San Joaquin system is characterized by substantially less freshwater runoff when compared to the Sacramento River basin, which is reflected in lower instream flows and frequently greater seasonal water temperatures that affect habitat quality and availability, reproductive success, survival, and overall abundance of Chinook salmon and steelhead within the San Joaquin basin. In addition, striped bass and other predatory fish are common in the lower reaches of the river, particularly in the spring months when juvenile salmonids are migrating downstream through these reaches.

Juvenile salmon mortality rates for fish that migrate downstream via the interior Delta are generally thought to be higher than for salmon that remain in the mainstem San Joaquin River based on results of CWT survival studies. To reduce salmonid migration via the interior Delta, a rock barrier was tested for several seasons at the Head of Old River. Results of CWT survival studies conducted using juvenile fall-run Chinook salmon released into the lower San Joaquin River show greater salmon survival when the temporary rock barrier was installed at the Head of Old River during the spring. More recently, a non-physical (e.g., bubble curtain) barrier was tested, which showed that the barrier was approximately 80% effective in deterring tagged juvenile salmon from entering Old River. However, the results also showed that predation on juvenile salmon within a scour hole in the San Joaquin River immediately downstream of the barrier altered salmon behavior and survival.

The 1995 Bay-Delta Water Quality Control Plan (D-1641) established the Vernalis Adaptive Management Plan (VAMP) to investigate the effects on juvenile salmonid survival of San Joaquin River flows at Vernalis, SWP and CVP exports, and the installation of physical barrier at Old River. Results of CWT survival studies performed from 2000 to 2006 as part of VAMP did not detect a statistically significant relationship between SWP and CVP exports and survival, although a positive relationship between San Joaquin River flow and survival has been identified in both VAMP survival studies and analysis of spring flows when juvenile salmonids were migrating.

Results of CWT survival studies have also detected a substantial decline in survival over time that was not related to river flow or exports, and thus appears to be in response to another factor. It has been hypothesized that in addition to ocean rearing conditions, increasing abundance of predatory fish over the past decade in the south Delta may be a factor contributing to the trend of declining salmon survival.

ES9. Salmonids in the Bay-Delta

The dominant factor affecting hydrodynamic conditions in the Delta is diurnal tidal action. The flow in Delta channels, as well as salinity intrusion into Suisun Bay and the Delta, is complex and driven to a large extent by tidal stage.

The Bay-Delta estuary serves as a migratory pathway for upstream immigrating adult and downstream emigrating juvenile salmonids and serves as short-term rearing habitat for juveniles of some salmonid species during their migration to the ocean.

Habitat in the Delta has been extensively modified through loss of most tidal wetlands and seasonally inundated floodplains that produced food as well as cover, velocity refugia, and rearing habitat for juvenile salmonids. In addition, species composition and trophic dynamics of the Bay-Delta food web have changed in response to the introduction of non-native fish, macroinvertebrates, aquatic plants, nutrients and contaminants. The recent expansion of submerged aquatic vegetation and increases in water clarity (due to reductions in turbidity) provide advantages to some introduced predators of juvenile salmonids.

SWP and CVP export operations, as well as in-Delta diversions affect conditions for migrating salmonids in the Delta. Depending on Delta inflows and the rate of in-Delta diversions and SWP and CVP exports, the direction and magnitude of flows in interior Delta channels can be altered and “reverse flows” can occur in Old and Middle Rivers (OMR). These flow modifications and other stressors affect hydrodynamics within the Bay-Delta and may impact the route selection, migration rate, and the behavioral response of juvenile salmon during migration through the Bay-Delta.

The scientific literature shows in-Delta survival of juvenile Chinook salmon during emigration through the Delta is related to fish size (larger juvenile salmon typically have higher survival rates) and Sacramento River flows, but are not significantly related to either the percentage of the CWT fish salvaged at the SWP and CVP export facilities (direct loses) or combined SWP and CVP export rates (indirect effect).

Additional studies have shown that the numbers of fish salvaged at the SWP and CVP export facilities provides an index of smolt survivorship to San Francisco Bay, and survivorship to the Delta has a much stronger influence on salvage than does export rate.

Ongoing research on the Delta Passage Model (DPM) suggests it will provide an opportunity to integrate various survival mechanisms, and make it possible to link route choices and survival in each route to flow and water operations in the Delta and estimate the magnitude of indirect mortality related to pumping volume.

ES10 Salmonids in the Ocean

Ocean conditions are an important factor impacting salmonid survival and abundance in terms of both successful rearing and ocean harvest of adults. Changes in ocean conditions can have a major impact on salmonid abundance that cannot be addressed through Delta or upstream flow changes.

Chinook salmon and steelhead spend a considerable portion of their lifecycle inhabiting coastal marine waters. Many salmonids enter the ocean as young of the year juveniles and reside in ocean waters for a period of 2 years or more. The survival of smolts at the time of ocean entry is thought to be the most critical phase for salmonids during their residence in the ocean.

During their ocean residency, juvenile and sub-adult salmonids forage and grow, and food availability is a critical factor influencing their growth and survival. Food availability in coastal marine waters varies in response to a number of factors that include coastal upwelling and ocean temperatures and currents. When productivity is low available food supplies for juvenile rearing salmonids is reduced resulting in reduced growth rates, increased mortality, and reduced adult abundance. When ocean productivity is good juvenile salmon survival is high resulting in strong year classes with high adult abundance.

Coastal upwelling and other oceanographic processes that influence productivity are characterized by cyclic patterns with recurrence intervals that may vary from years to decades. For example, ocean productivity was very low in the Gulf of the Farallones in 2005 and 2006 which was correlated with low adult salmon returns in 2007, 2008, and 2009. In response to the low numbers of adult salmon in the population the commercial and recreational fisheries were curtailed to protect the weak stocks.

Harvest of sub-adult and adult Chinook salmon in ocean commercial and recreational fisheries has a strong effect on the number of adults that return to spawn in the Central Valley. Harvest rates are regulated and have been reduced in recent years to help protect winter-run and spring-run Chinook salmon.

Central Valley Chinook salmon inhabiting the ocean include both wild fish and those produced in Central Valley fish hatcheries. Wild salmon populations cannot sustain harvest rates as high as for those stocks produced in hatcheries, but there is currently no program in place to distinguish wild from hatchery-produced fish. Mark-select fisheries (where all hatchery fish are marked) have been used as a management tool in the Northwest to protect wild salmon. Similar changes to ocean harvest management would improve abundance of wild Central Valley Chinook salmon.

ES11 Conclusion

Efforts to increase salmonid abundance in recent decades have resulted in some improvements, but significant annual population variability remains. As salmonids only spend between 2 and 9 percent of their lifespan within the Delta, proposed management actions focused on the estuary must be evaluated within the context of the species' entire lifecycles.

Ongoing research is improving our understanding of how various factors affect salmonid reproductive success, growth, health, and survival, but the complex interaction of those factors results in substantial uncertainty. Advances in applying acoustic tag technology, development and refining lifecycle models and other analytic tools, continued experience in applying results of monitoring to adaptive management decisions, and improved understanding of salmonid population dynamics serve to reduce uncertainty in identifying effective restoration and other actions that protect and improve conditions for Central Valley salmonids.

1 Overview of Central Valley Salmonids

This section describes the legal status of each Central Valley anadromous salmonid species, their life history characteristics, seasonal timing and geographic distribution of each species, and the seasonal distribution in habitat use for each salmonid. This information serves as part of the foundation and framework for understanding the relative contribution of river flows, Delta hydrodynamics, and exports, as well as stressors affecting the population dynamics of salmonids upstream of the Delta and within the ocean, on the survival and movement patterns of juvenile salmonids.

1.1 Legal Status

Sacramento River winter-run Chinook salmon were listed by the National Marine Fisheries Service (NMFS) as a threatened species in 1989 under emergency provisions of the federal Endangered Species Act (ESA), and formally listed as threatened in 1990 (55 FR 46515). The Sacramento River winter-run Chinook salmon Evolutionary Significant Unit (ESU) includes all naturally spawned populations of winter-run Chinook salmon in the Sacramento River and its tributaries as well as two artificial propagation programs: winter-run Chinook salmon produced from the Livingston Stone National Fish Hatchery and released as juveniles into the Sacramento River and winter-run Chinook salmon held in a captive broodstock program maintained at Livingston Stone National Fish Hatchery (70 FR 37160). The ESU consists of a single population that is confined to the upper Sacramento River. The ESU was reclassified as endangered under the federal ESA in 1994 (59 FR 440) due to increased variability of run sizes, expected weak returns as a result of two small year classes in 1991 and 1993, and a 99 percent decline between 1966 and 1991.

NMFS reaffirmed the listing of Sacramento River winter-run Chinook salmon as endangered in 2005 (70 FR 37160) and included the Livingston Stone National Fish Hatchery population within the listed population. Winter-run Chinook salmon are also classified as an endangered species under the California ESA. Critical habitat for winter-run Chinook salmon has been designated by NMFS and includes the Sacramento River, Delta, and northern portions of San Francisco Bay.

The Central Valley spring-run Chinook salmon ESU was listed as a threatened species under the federal ESA in 1999 (64 FR 50394). The ESU includes all naturally spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries in California, including the Feather River. In 2004, NMFS proposed that Central Valley spring-run Chinook salmon remain listed as threatened (69 FR 33102). This proposal was based on the recognition that the ESU continues to face risks from having a limited number of remaining populations (i.e., three existing populations from an estimated 17 historical populations), a limited geographic distribution, and potential hybridization with Feather River Hatchery spring-run Chinook salmon, which are genetically distinct from other populations in Mill, Deer, and Butte creeks. NMFS issued its final decision in 2005 to retain the status of Central Valley spring-run Chinook salmon as threatened (70 FR 37160). This decision also included the Feather River Hatchery spring-run Chinook salmon population as part of the ESU. Spring-run Chinook salmon are also listed as a threatened species under the California ESA. Critical habitat for spring-run Chinook salmon has been designated by NMFS and includes the Sacramento River, Delta, and northern portions of San Francisco Bay.

The fall- and late fall-run Chinook salmon ESU includes all naturally spawned populations of fall- and late fall-run Chinook salmon in the Sacramento and San Joaquin river basins and their tributaries east of Carquinez Strait (64 FR 50394). NMFS determined in 1999 that listing Central Valley fall- and late fall-run Chinook salmon was not warranted. The Central Valley fall- and late fall-run Chinook salmon ESU were reclassified as a federal Species of Concern (69 FR 19975) in 2004. The species are not listed under the

California ESA. Critical habitat has not been designated for either fall-run or late fall-run Chinook salmon because the species are not listed under the ESA; however, fall- and late fall-run Chinook salmon habitats are protected under the Magnuson-Stevens Fishery Conservation and Management Act as Essential Fish Habitat, which includes Central Valley rivers, the Delta, and San Francisco Bay.

The Central Valley steelhead distinct population segment (DPS) was listed by NMFS in 1998 as a threatened species under the federal ESA, and includes all naturally spawned populations of steelhead in the Sacramento and San Joaquin rivers and their tributaries, including the Bay-Delta (63 FR 13347). Steelhead from San Francisco and San Pablo bays and their tributaries are excluded from the Central Valley DPS, but are included in the Central California Coast DPS. In 2006, NMFS issued its final decision to retain the status of Central Valley steelhead as threatened (71 FR 834). This decision included the Coleman National Fish Hatchery and Feather River Hatchery steelhead populations. Critical habitat for Central Valley steelhead has been designated by NMFS and includes the Sacramento River, Delta, and San Francisco Bay.

1.1.1 Salmonid Life History

Winter-run, fall-run, late fall-run, and spring-run Chinook salmon and steelhead are anadromous species that spawn in freshwater but rear for a portion of their lifecycles in coastal marine waters (Williams 2006, Healey 1991). The general salmonid lifecycle is shown in Figure 1-1. The fecundity (number of eggs produced) by salmon and steelhead varies among species and individuals but typically is approximately 5,000 eggs/female (Williams 2006). For the population to remain stable, only two of these eggs need to survive to become reproductive adults (cohort replacement). A variety of mortality sources affect the numbers of eggs and juveniles that survive to adulthood and subsequently spawn (NMFS 2010). The seasonal timing, geographic distribution, life history characteristics, population dynamics, and environmental sensitivities of each individual species and their lifestages are important factors used in assessing the potential impacts stressors have on the species.

1.1.1.1 Adult Salmonid Migration

Chinook salmon and steelhead migrate upstream from the ocean, through the Delta, and into Central Valley rivers during the fall, winter, and spring months (the name for Chinook salmon, such as winter-run, reflects the seasonal timing of adult upstream migration) depending on the species. Chinook salmon exhibit two characteristic freshwater life history types (Williams 2006, Healey 1991). Stream-type adult Chinook salmon enter freshwater months before spawning, and their offspring reside in freshwater one or more years following emergence. Ocean-type Chinook salmon, in contrast, spend significantly less time in freshwater, spawning soon after entering freshwater as adults and migrating to the ocean as juvenile young-of-the-year or yearling smolts within their first year. (Healey 1991) Appropriate stream flows and cool water temperatures upstream are more critical for the survival of Chinook salmon exhibiting the stream-type life history behaviors due to their residence in freshwater both as adults and juveniles over the warmer summer months. Some adult species (e.g., fall-run and late fall-run Chinook and steelhead) are sexually mature when they enter freshwater, while other adult species (e.g., spring-run and winter-run Chinook salmon) are sexually immature and hold in upstream freshwater for a period of time before spawning.

1.1.1.2 Spawning

Chinook salmon spawn in clean, loose gravel in swift, relatively shallow riffles; or along the margins of deeper river reaches where suitable water temperatures, depths, and velocities favor redd (gravel nest) construction and oxygenation of incubating eggs. Spawning occurs in the upper reaches of rivers and streams in areas characterized by gravels with interstitial spaces that allow water to easily flow through the spawning gravels within the redd and a low percentage of fine material with suitable size, in areas where water temperatures during spawning are cool (preferably less than 57 F [Williams 2006]). The female digs a shallow depression in the gravel (redd) where the eggs are deposited and fertilized by the male. The fertilized eggs are then covered by a shallow layer of gravel. Water flow through the gravel and water temperatures are two factors that affect hatching success (Williams 2006). After hatching, the young salmonids (alevin stage) remain in the gravel redd until they have absorbed the yolk-sac and begin to emerge into the surface waters.

1.1.1.3 Fry Emergence and Rearing

Young salmonids (fry) typically inhabit river and stream areas where water depths are relatively shallow and water velocities are reduced (e.g., channel margins) and where they can feed on small zooplankton and macroinvertebrates (Bjornn and Reiser 1991, Reiser and Bjornn 1979). Fry seek streamside habitats containing beneficial aspects, such as riparian vegetation and associated substrates, which provide aquatic and terrestrial invertebrates, predator avoidance cover, and slower water velocities for resting (NMFS 1996). Higher juvenile salmon growth rates have been associated with shallow water habitats, as opposed to the deeper main river channels, partially due to greater prey consumption rates, as well as favorable environmental temperatures (Sommer *et al.* 2001a,b). As the juveniles grow, they tend to inhabit deeper water areas with higher velocities where they forage on macroinvertebrates and drift insects (Williams 2006). For some salmonid species, such as fall-run and winter-run Chinook salmon, juvenile rearing in freshwater is relatively short (months), with some juveniles rearing in upstream areas and migrating downstream as smolts (physiologically capable of the transition from freshwater to saltwater) and others in the population migrating downstream shortly after emergence as fry to rear in the lower reaches of the rivers and the Delta until ready to move into saltwater (Williams 2006). In other species, such as late fall-run and spring-run Chinook salmon and steelhead, the juveniles rear in the upstream river habitat for 1 year before migrating downstream through the Delta into the ocean.

1.1.1.4 Ocean Lifecycle

Juvenile salmonids typically rear for at least 2 to 3 years in coastal marine waters, where they feed on marine macroinvertebrates (e.g., krill, amphipods, squid) and small fish (Williams 2006). Sub-adult and adult Chinook salmon are harvested in coastal commercial and recreational fisheries, while steelhead (because of their diet) are not vulnerable to ocean harvest. Both adult Chinook salmon and steelhead are harvested in relatively low numbers in the inland recreational fisheries within San Francisco, San Pablo, and Suisun bays, the Delta, and Central Valley rivers.

Central Valley Chinook salmon begin their ocean life in the coastal marine waters of the Gulf of the Farallones from where they distribute north and south along the continental shelf primarily between Point Conception and Washington State (Healey 1991). Upon reaching the ocean, juvenile Chinook salmon feed on larval and juvenile fishes, plankton, and terrestrial insects (Healey 1991, MacFarlane and Norton 2002). Chinook salmon grow rapidly in the ocean environment, with growth rates dependent on water temperatures and food availability (Healey 1991). The first year of ocean life is considered a critical period of high mortality for Chinook salmon that largely determines survival to harvest or spawning (Beamish and Mahnken 2001, Quinn 2005).

Central Valley Chinook salmon remain in the ocean for 2 to 5 years. Fall-run and late fall-run Chinook salmon mature in the ocean before returning to freshwater to spawn. Spring-run and winter-run Chinook salmon return to freshwater as immature adults as indicated by the several months they spend in upstream rivers before spawning. Ocean conditions during the salmonid ocean residency period are important, as exemplified by the substantial adverse effect of the 1983 El Niño on the size and fecundity of Central Valley fall-run Chinook salmon (Wells *et al.* 2006).

1.1.2 Seasonal Timing and Geographic Distribution of Salmonids

The seasonal timing and geographic distribution of Central Valley salmonids within the Delta and its watersheds are described below. Additional information on the life history, habitat requirements, population dynamics, and factors affecting Central Valley salmonids is presented by Williams (2006), Healey (1991) McEwan (2001) and others.

1.1.2.1 Winter-run Chinook Salmon

Adult winter-run Chinook salmon migrate upstream from the Pacific Ocean through the Bay-Delta estuary during November through March moving upstream into the Sacramento River near Redding during December through April with the greatest movement during late-February through late-March. The adults are sexually immature when migrating upstream and hold in the mainstem river for a period of months prior to spawning. Spawning occurs in the mainstem Sacramento River downstream of Keswick Dam from April through August with the greatest spawning activity during May. Egg incubation occurs between April and late-September. Juvenile rearing and emigration typically occurs between July and February in the upper river with juvenile migration downstream through the Delta between late-November and May.

Winter-run Chinook salmon spawning is currently limited to the mainstem Sacramento River in the reach from Keswick Dam to Red Bluff (Figure 1-2), although the actual distribution of spawning and egg incubation within the reach varies among years in response to water temperatures, adult abundance, and other factors (Williams 2006). During the seasonal migration period, juvenile and adult winter-run Chinook salmon use the Sacramento River, Delta, and downstream bays (e.g., Suisun, San Pablo, and central San Francisco bays) as juvenile rearing habitat and as a migratory corridor. Critical habitat for winter-run Chinook salmon includes the Sacramento River, Delta, and downstream bays to the Golden Gate Bridge (58 FR 33212, 1993).

1.1.2.2 Spring-run Chinook Salmon

Adult spring-run Chinook salmon migrate upstream from the Pacific Ocean through the Bay-Delta estuary during January through mid-May, moving upstream into the Sacramento River near Redding and major tributaries such as Mill, Deer, and Butte creeks and the Feather River during late-March through September with the greatest movement during May. The adults are sexually immature when migrating upstream and hold in the mainstem river and tributaries for a period of months prior to spawning. Spawning typically occurs during late-August through September with the greatest spawning activity during September. Egg incubation occurs between September and January. Juvenile rearing typically includes one portion of the population moving downstream as fry and another portion rearing within the upper reaches of the river and tributaries for 1 year and then migrating downstream as smolts between approximately September and early May. Juvenile migration downstream through the Delta typically occurs between late-November and August although the majority of juvenile migration occurs during the late-winter and spring.

Spring-run Chinook salmon inhabit a variety of Central Valley rivers and creeks, including the mainstem Sacramento River downstream of Keswick Dam, Clear Creek, the Feather River, and tributaries such as Mill, Deer, Antelope, Big Chico, Battle, and Butte creeks. The majority of spring-run Chinook salmon adults migrate into Sacramento River tributaries such as Mill, Deer, and Butte creeks for adult holding, spawning, and juvenile rearing. The geographic distribution of spring-run Chinook salmon spawning includes both the mainstem Sacramento River and a number of major tributaries, as shown in Figure 1-3.

During the seasonal periods of adult and juvenile migration, the Sacramento River, Delta, and downstream bays serve as juvenile rearing habitat and a migratory corridor for both adult and juvenile spring-run Chinook salmon. Critical habitat for spring-run Chinook salmon includes the Sacramento River, tributaries supporting spring-run such as Deer, Mill, and Butte creeks, the Delta, and downstream bays to the Golden Gate Bridge (70 FR 52488, 2005).

1.1.2.3 Fall- And Late Fall-Run Chinook Salmon

Historically, Central Valley fall-run Chinook salmon spawned in all major tributaries, as well as the mainstem of the Sacramento and San Joaquin rivers. A large percentage of fall-run Chinook spawning in the Sacramento and San Joaquin rivers historically occurred in the lower gradient reaches of the rivers downstream of sites now occupied by major dams. As a result of the geographic distribution of spawning and juvenile rearing areas, fall-run Chinook salmon populations in the Central Valley were not as severely affected by early dam building as were spring- and winter-run Chinook salmon and steelhead that used higher elevation habitat for spawning and rearing (Yoshiyama *et al.* 1998).

Fall-run Chinook salmon inhabit a variety of Central Valley rivers and creeks, including the mainstem Sacramento River downstream of Keswick Dam, the Feather and American Rivers, the Mokelumne, Tuolumne, Merced, and Stanislaus Rivers, and other tributaries. The geographic distribution of fall-run Chinook salmon spawning includes both the mainstem Sacramento River and a number of major tributaries, as shown in Figure 1-4. The majority of fall-run Chinook salmon adults migrate into the Sacramento River and its tributaries for adult holding, spawning, and juvenile rearing.

Central Valley fall-run Chinook salmon exhibit an ocean-type life history. Adult fall-run Chinook salmon migrate through the Delta and into Central Valley rivers from July through December and spawn from October through December. Peak spawning activity usually occurs in October and November. The life history characteristics of late fall-run Chinook salmon are not well understood; however, they are thought to exhibit an ocean-type life history. Adult late fall-run Chinook salmon migrate through the Delta and into the Sacramento River from October through April and may wait 1 to 3 months before spawning from January through April. Peak spawning activity occurs in February and March. Chinook salmon typically mature between 2 and 6 years of age (Myers *et al.* 1998). The majority of Central Valley fall-run Chinook salmon spawn at age 3.

Central Valley fall-run Chinook salmon fry migrate downstream into the lower rivers and estuary in January, with peak fry abundance occurring in February and March. A later emigration of fall-run Chinook salmon smolts occurs from April through June. Fall-run Chinook salmon fry continue to rear in the upper estuary and emigrate as smolts during the normal smolt emigration period. Fall-run Chinook salmon smolts arriving in the estuary from upstream rearing areas typically migrate quickly through the Delta and Suisun and San Pablo bays.

The entire population of the Central Valley fall-/late fall-run Chinook salmon ESU pass through the Delta as upstream migrating adults and emigrating juveniles. Young fall/late fall-run Chinook salmon migrate through the Delta towards the Pacific Ocean and use the Delta for rearing to varying degrees, depending on their life stage (fry vs. juvenile) and size, river flows, and time of year.

Late fall-run Chinook salmon spawning is currently limited to the mainstem Sacramento River in the reach from Keswick Dam to Red Bluff (see Figure 1-2) and Battle Creek. Juvenile late fall-run Chinook salmon rear in the upper Sacramento river and migrate downstream as yearlings.

1.1.2.3.1 Central Valley Steelhead

Adult steelhead migrate upstream from the Pacific Ocean into San Pablo, Suisun and other bays, during the late summer and early fall. They appear to forage in these more saline waters for a period of time before migrating upstream into the rivers during the late fall and winter when upstream water temperatures are more suitable. Spawning typically occurs in the mainstem Sacramento River downstream of Keswick Dam between late-November and April with the greatest spawning activity during the period from January through March. Egg incubation occurs between April and late-September. Juvenile rearing and emigration typically occurs between December and April in the upper river. Juvenile steelhead rear within the river year-round for a period of typically 1 to 2 years before migrating downstream to the ocean. Juvenile migration downstream through the Delta typically occurs between late-September and May. The seasonal timing of migration, spawning and egg incubation, and juvenile emigration varies somewhat among Central Valley rivers (McEwan 2001, McEwan and Jackson 1996).

Central Valley steelhead are broadly distributed within many of the waterways shown in Figure 1-5, including the mainstem Sacramento River, many of the upstream tributaries, and the Feather, Yuba, American, Mokelumne, and Cosumnes rivers. Steelhead also inhabit Clear, Mill, Deer, Antelope, Butte creeks, and other smaller tributaries. A modest number of wild steelhead is also produced in the lower American, Mokelumne, Cosumnes, and Stanislaus rivers. Recent evidence also shows steelhead occurring on other tributaries to the lower San Joaquin River. Critical habitat for Central Valley steelhead includes the Sacramento and San Joaquin rivers and their tributaries supporting steelhead, the Delta, and downstream bays to the Golden Gate Bridge (70 FR 52488, 2005).

1.1.3 Seasonal Distribution in Habitat Use

Chinook salmon and steelhead inhabit the Delta for only a short period of their respective life cycles. A generalized approximation of the duration that salmon and steelhead inhabit each of their habitats is summarized in Tables 1-1 and 1-2, below, based on general life history information from Williams (2006), Healey (1991) McEwan (2001) and others. The actual periods of occupation in each habitat vary by individual and in response to environmental conditions, growth rates, maturation, and other factors. These figures show that salmonids use Delta waters as habitat for only a short duration (typically 2-9 percent of their total life cycle in a typical 3-year life span), with the majority of their lives spent in the ocean. Upstream, Delta and marine habitats all serve important functions in the population dynamics of the species, although factors affecting upstream and ocean conditions have a particularly strong impact on the reproductive success and abundance of salmonids in the Central Valley.

Table 1-1. Generalized estimates of the number of weeks a 3-year-old salmonid spends in upstream, Delta, and ocean habitats.

Lifestage	Fall-run Chinook	Late Fall-run Chinook	Spring-run Chinook	Winter-run Chinook	Central Valley Steelhead
Upstream adult migration through the Delta	1-2	1-2	1-2	1-2	1-2
Adult migration and upstream holding	2-4	2-4	20-24	28-32	2-4
Spawning and egg incubation	10-12	10-12	10-12	10-12	10-12
Juvenile rearing in upstream areas	16-20	42	4-42	4-24	42-104
Juvenile migration and rearing in the Delta	2-12	2-4	2-12	2-12	2-4
Juvenile and sub-adult rearing in the ocean	106-125	92-99	64-119	74-111	30-99

Table 1-2. Generalized estimates of the percentage of its life cycle a 3-year salmonid spends in upstream, Delta, and ocean habitats

Percentage of a 3-year Life Span:	Fall-run Chinook	Late Fall-run Chinook	Spring-run Chinook	Winter-run Chinook	Central Valley Steelhead
Inhabiting Upstream Areas	18-23%	35-37%	22-50%	27-44%	35-77%
Inhabiting the Bay Delta	2-9%	2-4%	2-9%	2-9%	2-4%
Inhabiting the Ocean	68-80%	59-64%	41-76%	47-71%	19-64%

Note: These percentages of time when salmonids occupy various habitats are generalized. Actual timing may vary among runs and years in response to life history diversity and environmental conditions.

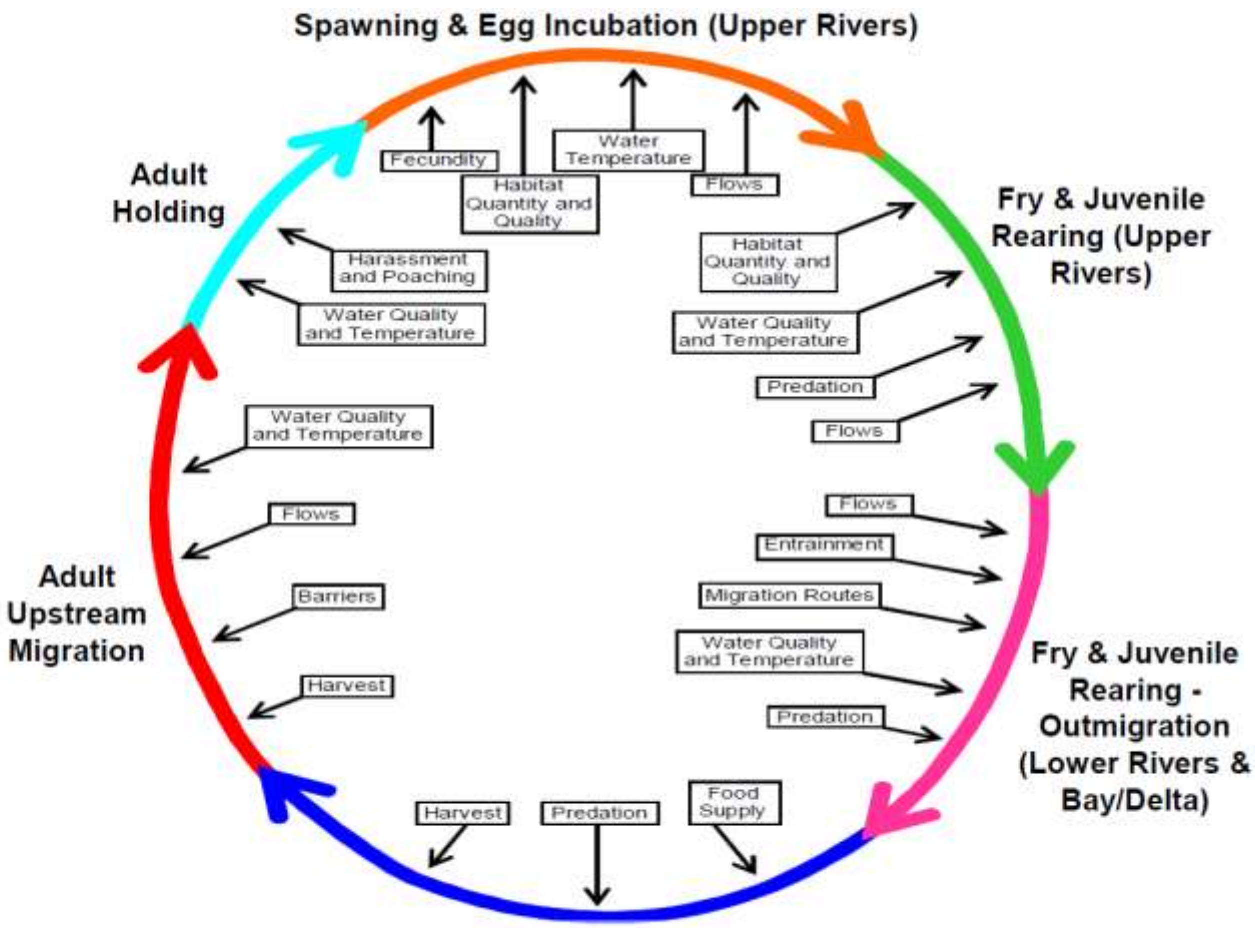

Figure 1-1. Generalized life history of Central Valley Chinook salmon and steelhead (Source: Vogel 2011). On the Sacramento River upstream habitat is defined as areas upstream of Sacramento. On the San Joaquin River upstream habitat is defined as areas upstream of Vernalis. The Delta is defined for this purpose as the area downstream of Sacramento and Vernalis to Chipps Island. The estuary is defined for this purpose as the area downstream of Chipps Island to the Golden Gate. Ocean rearing habitat is defined as coastal marine waters outside of the Golden Gate.

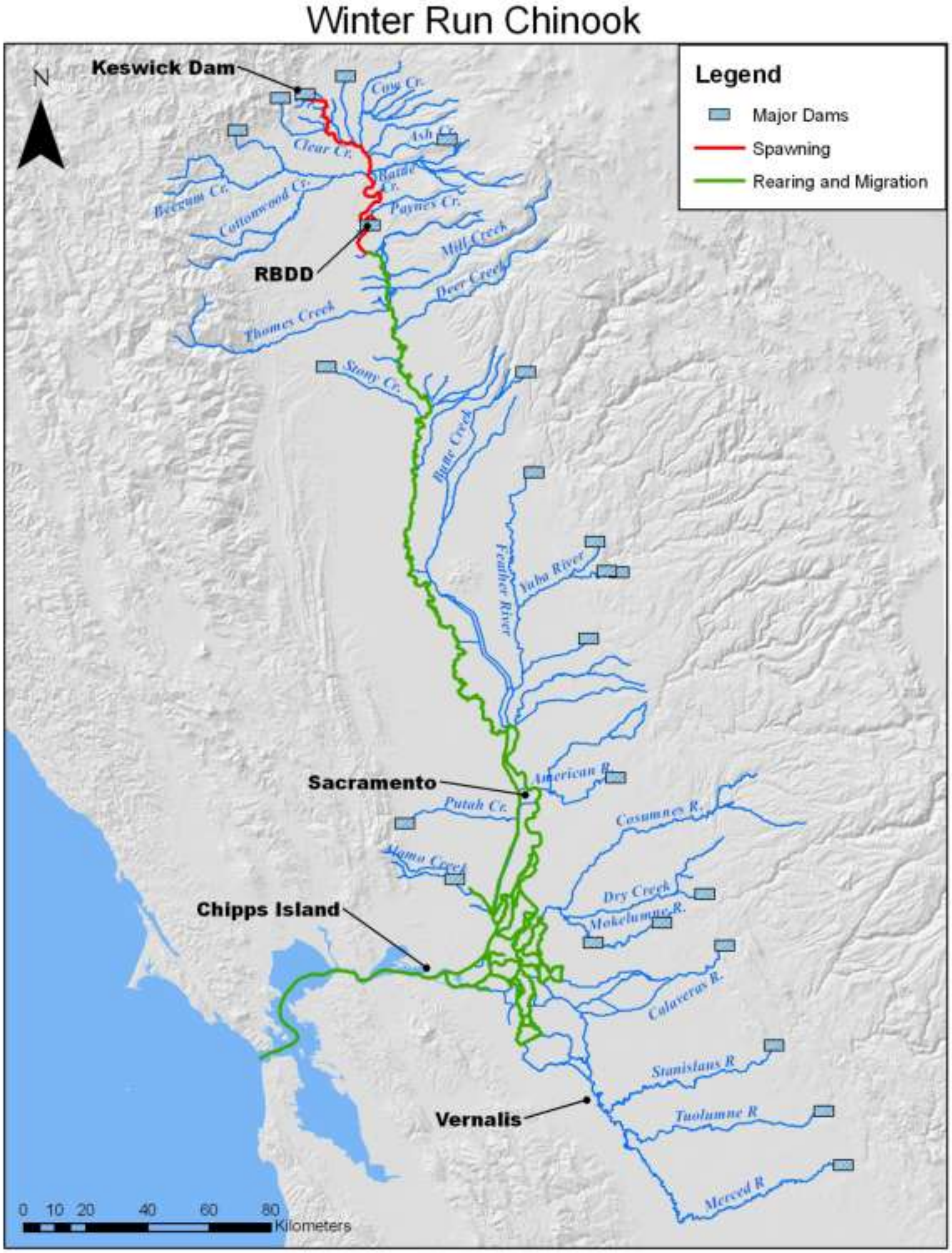

Figure 1-2. Geographic distribution of winter-run Chinook salmon in the Central Valley.

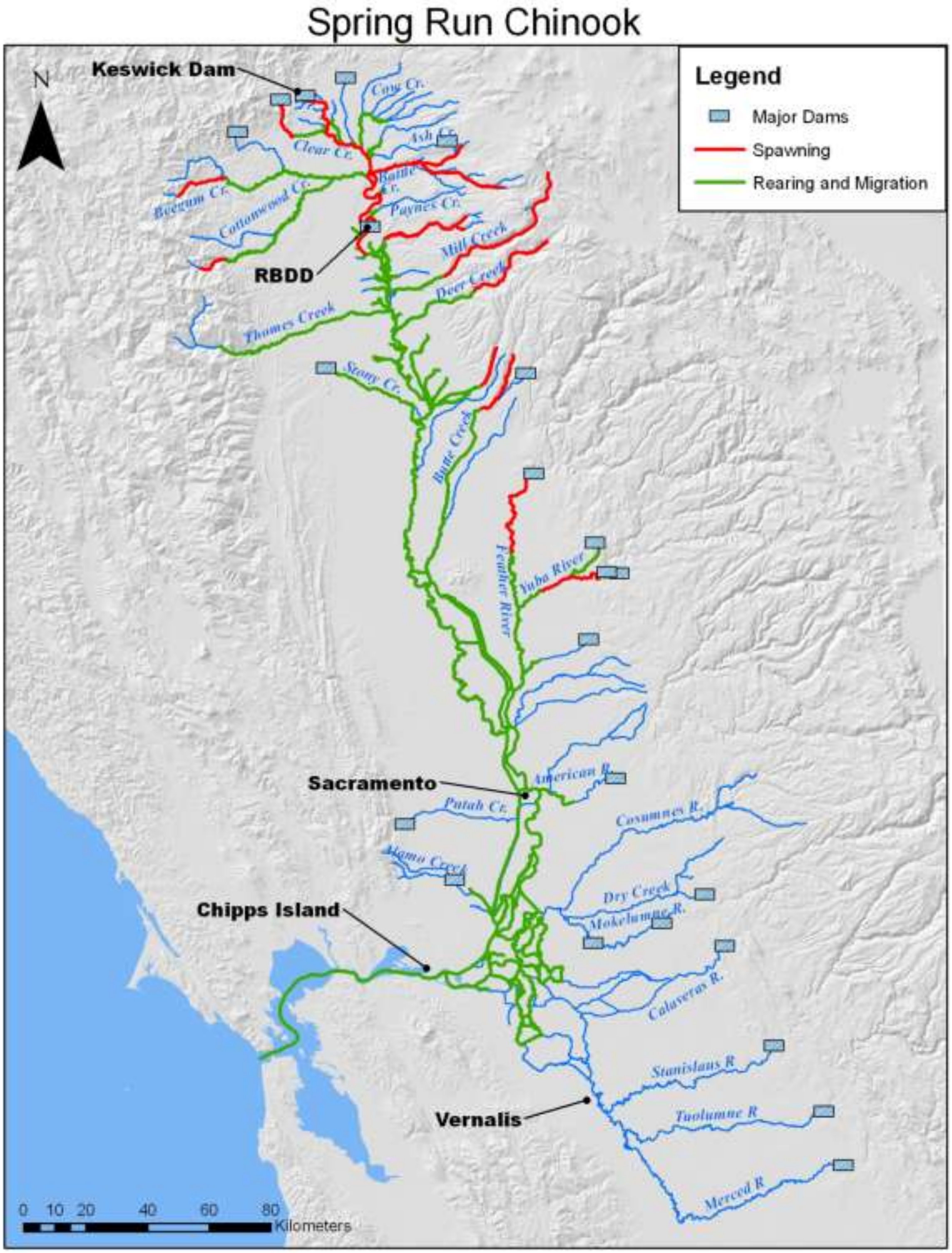

Figure 1-3. **Geographic distribution of spring-run Chinook salmon in the Central Valley.**

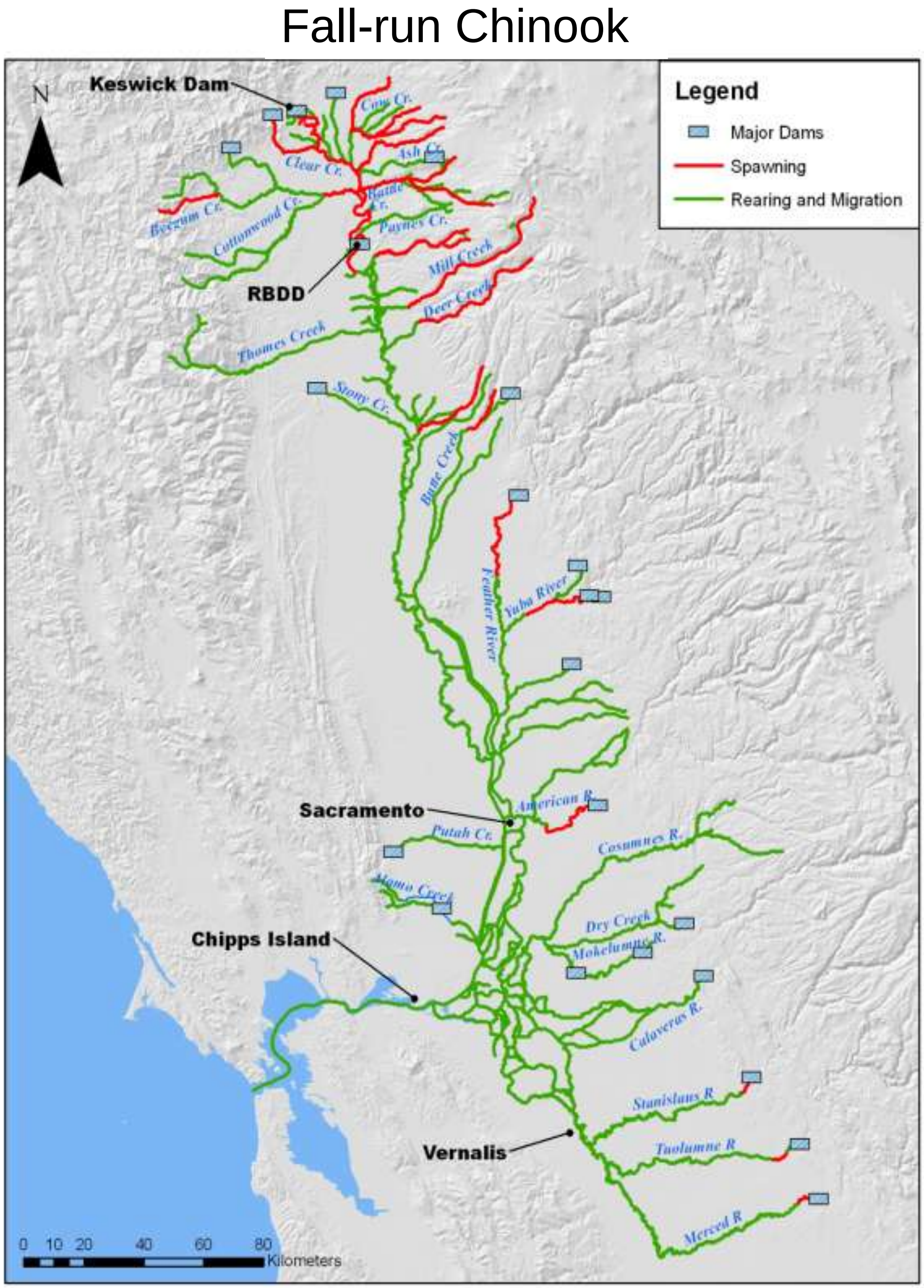

Figure 1-4. Geographic distribution of fall-run Chinook salmon in the Central Valley.

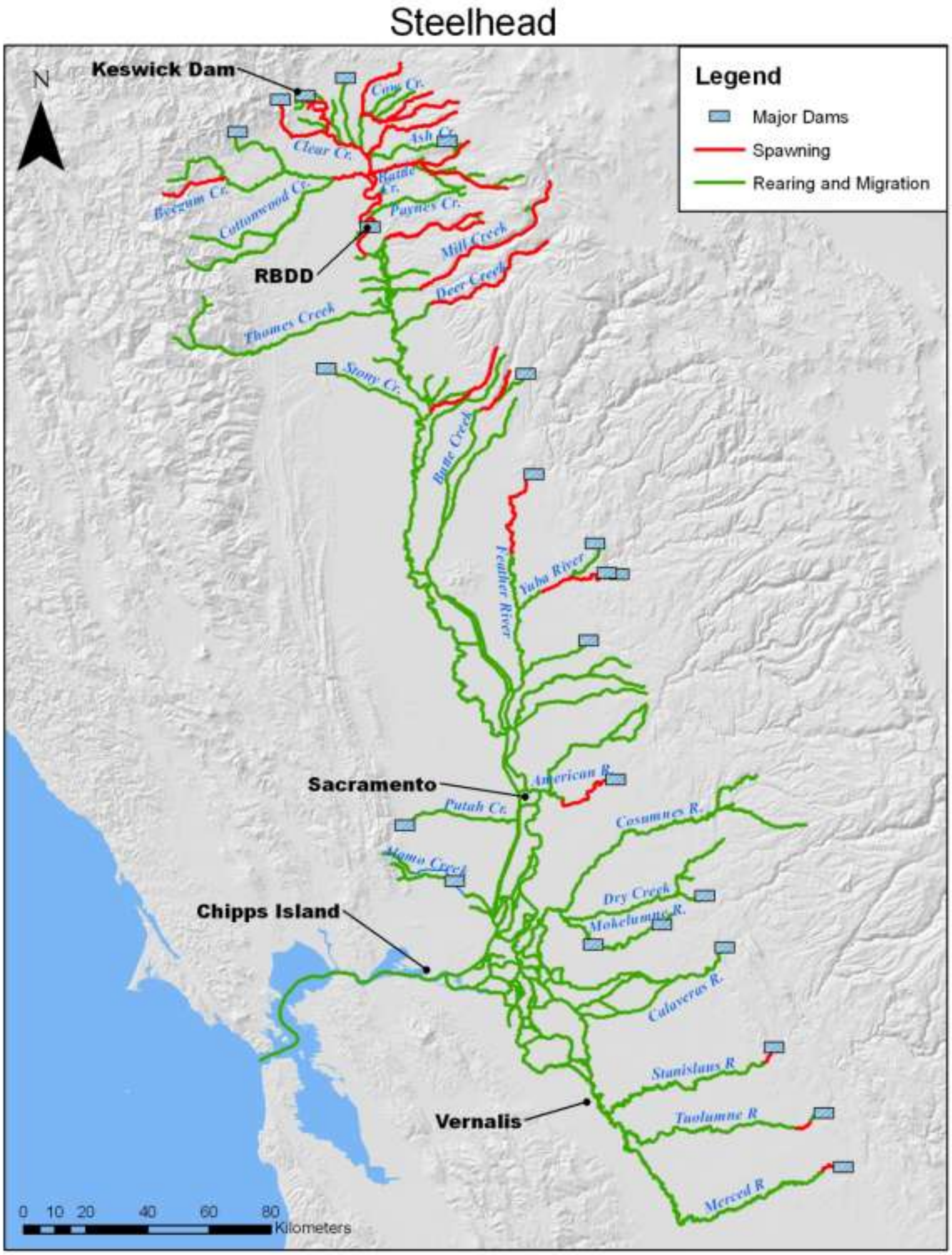

Figure 1-5. Geographic distribution of steelhead in the Central Valley.

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2 Stressors Affecting Central Valley Salmonids

The survival, growth, reproductive success, and overall abundance of Central Valley salmonids are affected by a wide variety of stressors (NMFS 2010). Many of these stressors occur independent of flow conditions, while other stressors are affected by flows. Many stressors with a strong effect on salmonid population dynamics and abundance occur in upstream spawning and juvenile rearing habitat, as well as in coastal marine rearing habitat for juvenile and sub-adult salmonids. Factors affecting salmonid survival also occur in the Delta. These diverse stressors affect salmonids in different habitats and at different lifestages in a complex, interacting manner. Numerous restoration, management, and regulatory actions have been taken to improve and protect salmonids in habitats located upstream of the Delta, within the Delta, and within the ocean, as discussed in Section 3, but the complexities involving stressors create uncertainty regarding how any particular management action may affect the species on a holistic level. Therefore, as recommended by NMFS (2010), to the greatest extent possible, proposed management actions must be evaluated within the context of the array of stressors acting on the species within the framework of the lifecycle of the species.

This section provides an overview of stressors affecting Central Valley salmonids, discusses changes to the six Primary Constituent Elements for these salmonids identified by NMFS (2010), and discusses the risks to salmonids from predation by non-native species.

2.1 Overview of Stressors

Historical changes in the Bay-Delta landscape have affected numerous components of salmonid habitat. The complex assemblage of floodplains, freshwater and tidal wetlands, open water, and upland habitats historically provided valuable space for rearing, spawning, migration, and refuge from predators for salmonids. The extensive changes to the Delta landscape have reduced, fragmented, and isolated these habitats. Where land and water were once intricately connected, in the current Bay-Delta landscape, levees maintain complete separation in most Delta areas of the watershed.

The draft salmonid recovery plan (NMFS 2010) and Bay Delta Conservation Plan (BDCP) draft Effects Analysis (BDCP 2010) discuss many of the stressors that adversely impact salmonids. These stressors include, but are not limited to, the following (not in order of importance):

- Loss of access to higher elevation habitat in the upper watersheds as a result of dams;
- Exposure to elevated water temperatures, particularly in the upper river reaches where spawning and egg incubation occur;
- Exposure to elevated water temperatures upstream during juvenile rearing and over summering (especially for juvenile steelhead) and in the Delta during downstream juvenile migration;
- Reductions in escapement of adults to spawning grounds, contributing to reduced juvenile production in the subsequent generation (stock-recruitment);
- Exposure to adverse flow conditions such as large fluctuations in flows and high scouring flows during egg incubation;
- Reverse flow conditions in the central and south Delta;
- Entrainment into SWP and CVP export facilities, as well as a large number of other diversions;
- Spawning gravel quality and availability;

- Reduced food production in upstream juvenile rearing habitats;
- Loss of riparian habitat from levees and bank protection;
- Loss of access to seasonally inundated floodplain habitat;
- Loss of access to shallow water low velocity juvenile rearing habitat from levees and bank protection;
- Loss of tidal marsh habitat for juvenile rearing and food production;
- Exposure to adverse water quality conditions including point and non-point source pollutants, depressed dissolved oxygen concentrations, and other constituents;
- Loss of spawning and rearing habitat due to erosion and sedimentation;
- Loss of spawning gravel and rearing habitat as a result of mining as well as channel modifications due to dredging and dredge spoil disposal;
- Migration delays and exposure to increased predation due to physical river passage impediments;
- Predation mortality by native and non-native fish and other wildlife including species that are managed as a sport fishing resource such as striped bass and largemouth bass;
- Commercial, recreational, by catch, and illegal harvest;
- Effects of hatchery operations and artificial propagation;
- Competition and predation by introduced exotic species;
- Infectious disease (especially in the hatcheries);
- Climate variation including droughts and flood flows; and
- Ocean conditions that affect productivity of food resources and predation.

2.2 Changes to Primary Constituent Elements

Recovery planning for Central Valley salmonids includes six PCEs identified by NMFS (2010a) and considered essential for conservation of Central Valley salmonids: (1) freshwater spawning sites, (2) freshwater rearing sites, (3) freshwater migration corridors, (4) estuarine areas, (5) nearshore marine areas, and (6) offshore marine areas. As explained below, the composition and overall extent of these habitat areas have changed over time (refer to the discussion in Section 1 regarding salmonid life history for a further discussion of habitat requirements).

2.2.1 Spawning Habitat

Chinook salmon and steelhead spawning sites include those reaches with instream flows, water quality, and substrate conditions suitable to support spawning, egg incubation, and larval development. Dam construction has not only blocked salmonid access to suitable upstream spawning habitat, it has also affected upstream flows and water temperatures, spawning gravel recruitment and other habitat conditions where salmonid spawning now occurs downstream of dams (NMFS 2010a).

2.2.2 Freshwater Rearing Habitat

Rearing habitat quality is strongly affected by habitat complexity, food supply, and vulnerability to avian and piscivorous predators. The channeled, leveed, and riprapped river reaches and sloughs common in the Sacramento and San Joaquin rivers and throughout the Delta typically have low habitat diversity and complexity, low abundance of food organisms, and offer little protection from predation by fish and birds.

Freshwater rearing habitat has a high conservation value because salmonid juvenile life stage is dependent on the function of this habitat for successful growth and survival and recruitment to the adult population (Williams 2006). A more thorough evaluation of the potential benefits to salmonids of improved floodplain habitat is presented in Attachment A.

Waterway channelization, dam operations, reduction in gravel and large woody debris, loss of riparian vegetation, water diversions and other control features such as weirs and gates, are examples of changes that have affected habitat quality, availability, and function for juvenile salmonid rearing (NMFS 2010a). As an example, over the past 150 years, approximately 1,335 miles of levees were constructed in the Delta, and many in-Delta channels were widened, straightened, deepened, and connected, and in some instances gated (The Bay Institute 1998). These man-made changes have collectively altered the pattern and extent of diurnal tidal flows. Most upstream rivers and many of the contributing streams have been modified with dams, diversions, or other “improvements” that have separated channels from their floodplains, thus changing inflow patterns and reducing sediment and nutrient inputs to the ecosystem.

2.2.3 Freshwater Migration Corridors

Freshwater migration corridors for Chinook salmon and steelhead, including river channels and Delta waterways, support mobility, survival, and food supply for juveniles and adults. To be most beneficial to salmonids, migration corridors should be free from obstructions (passage barriers and impediments to migration), have favorable water quantity (instream flows) and quality conditions (seasonal water temperatures), and contain natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks. As discussed above, a number of Delta channels have been gated, and most upstream rivers and many of the contributing streams have been modified with dams, diversions, or other structures that can affect migration by not allowing for adequate passage or providing suitable migration cues; in some instances, they also may provide false attraction (Mysick 2001).

Salmonid access to and use of wetlands and floodplain habitat is also important (Bottom *et al.* 2011, Sommer 2001a,b, 2004). Floodplain inundation provides rearing habitat for juvenile salmonids that take advantage of the high productivity on the floodplain (Poff *et al.* 1997; Sommer *et al.* 2001a, b; Feyrer *et al.* 2004; Schramm and Eggleton 2006; Grosholz and Gallo 2006). During periods of connection between floodplains and rivers, juvenile salmonids can move on and off the floodplain to forage or rear (Moyle *et al.* 2007). The low-velocity, shallow, and vegetated conditions of the floodplain serve also as a refuge from the fast, turbid waters of the river during high flows (Sommer *et al.* 2001a; Jeffres *et al.* 2008).

Before European settlement, the Sacramento and San Joaquin rivers flowed through approximately 400,000 acres of wetlands and other aquatic habitats in the Bay-Delta (Lund *et al.* 2007, The Bay Institute 1998). The primary landscapes included flood basins in the north, tidal islands in the central Bay-Delta, and a complex network of channels formed by riverine processes in the south. Over the past 150 years, however, approximately 95 percent of the tidal wetlands were lost due to reclamation and development (The Bay Institute 1998).

2.2.4 Estuarine Areas

Estuarine migration and juvenile rearing habitats should be free of obstructions (i.e., dams and other barriers) and provide suitable water quality, water quantity (river and tidal flows), and salinity conditions to support juvenile and adult physiological transitions between fresh and salt water. Natural cover, such as submerged and overhanging large wood, aquatic vegetation, and side channels, provide juvenile and adult foraging. Estuarine areas function to support juvenile salmonid growth, smolting, avoidance of predators, and provide a transition to the ocean environment.

Channelization, levee construction and stabilization, wetland reclamation, water diversions, discharges, marinas and other structures, as well as loss of cover and habitat complexity are examples of landscape changes that have affected habitat quality, availability, and functions of the Bay-Delta estuary as habitat for salmonids (NMFS 2010a).

2.2.5 Ocean Habitats

Biologically productive coastal waters are an important habitat component for Central Valley Chinook salmon and steelhead. Nearshore marine rearing areas include those habitats free from obstructions (i.e., man-made sea walls and jetties) with water quality conditions and forage (including marine invertebrates and fishes) that support salmonid growth and maturation.

Offshore marine areas with water quality conditions and forage, including aquatic invertebrates and fishes, supporting salmonid growth and maturation are important in determining survival and growth and ultimately adult abundance. Results of various analyses (e.g., Lindley *et al.* 2009, Wells *et al.* 2006) have shown the importance of coastal upwelling and ocean current patterns on phytoplankton and zooplankton production in coastal waters and subsequent survival and abundance of salmonids.

In addition to natural upwelling and coastal currents that affect habitat conditions and food supplies for salmonids rearing in the ocean, commercial and recreational Chinook salmon harvest directly affects survival and abundance of Central Valley salmon (Williams 2006).

2.3 Risks from Predation by Non-Native Fish Species

A growing body of scientific evidence strongly suggests that predation of juvenile salmonids by the increasing numbers of largemouth bass and other non-native fish species in the Delta is a major factor contributing to reduced survival and abundance of Chinook salmon and Central Valley steelhead. A number of non-native predatory fish inhabit the Delta, including largemouth bass, striped bass, and sunfish. Fishery surveys are periodically conducted to collect data that can be used to assess general patterns in the abundance, size, distribution, and relative species composition of the Delta fish community. Relevant data are available from several time periods over the past 3 decades: 1980-83, 1995, 1997, and 1999, 2001-2003, and 2008-2010 (Conrad *et al.* 2010a). These fishery surveys differed from traditional midwater trawl sampling in that they used a boat-mounted electrofisher that sampled fish in areas near shorelines, adjacent to in-river structures, and where submerged aquatic vegetation (SAV) (e.g., *Egeria densa*) is common. In recent years, these surveys have been used to better document the relationship between SAV and non-native predatory fish (Feyrer and Healey 2003, Brown and Michniut 2007, Nobriga and Feyrer 2007, Nobriga *et al.* 2005).

These fishery survey results show an increasing abundance trend in largemouth bass and sunfish over the last three decades. These data show that sunfish abundance (catch per unit effort [CPUE]) increased from an average of 0.04 in 1980-1983 to approximately 0.11 in 2008-2010 (Figure 2-1).

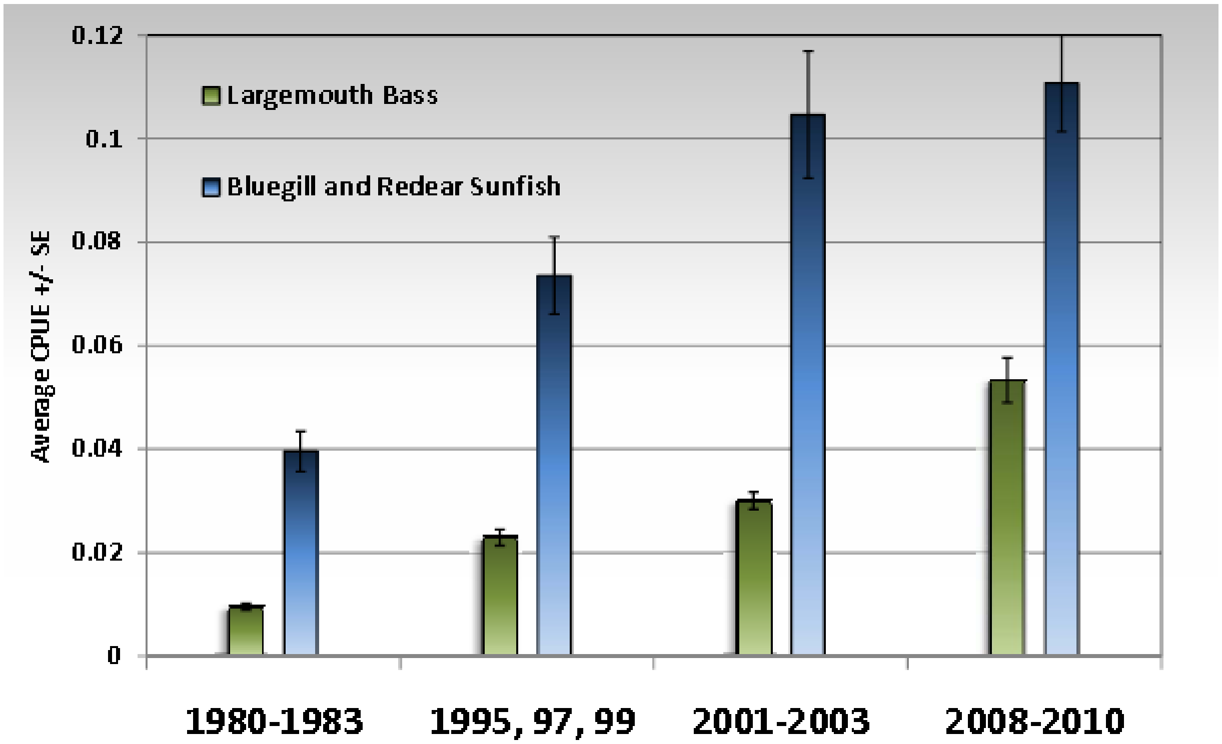

Figure 2-1. Trends in largemouth bass and sunfish abundance in the Delta (Source: Conrad *et al.* 2010a).

This represents a nearly 300 percent increase in sunfish abundance in the Delta in less than 30 years. Abundance trends for largemouth bass are even more stark; CPUE for the species in the 1980-1983 period averaged approximately 0.01, but increased to approximately 0.055 in 2008-2010 (Figure 2-2). This reflects a more than five-fold increase in abundance for the species in three decades. Fish salvage monitoring at the SWP and CVP export facilities has also shown a substantial increase in the number of largemouth bass collected in recent years, particularly since the early 1990s (Nobriga 2009).

Increased largemouth bass abundance observed in Delta fishery surveys is consistent with growing Delta bass tournament fishing days in the last 25 years (Figure 2-2). Bass fishing tournament days increased from fewer than 10 days in 1986 to approximately 300 days in 2008-2009 (Conrad *et al.* 2010b). That is, largemouth bass tournament fishing has increased by a factor of approximately 30 over the past 2 decades and now supports a major recreational fishery. The Delta is now considered a world-class largemouth bass fishery. Thousands of anglers fish Delta waters, and nationally televised (e.g., Bass Masters), as well as local and regional tournaments are conducted throughout the year.

In addition to the increasing trend in largemouth bass abundance, the fishery surveys also show that the size of largemouth bass inhabiting the Delta has increased significantly in the past decade (Figure 2-3). In particular, there has been a marked increase in the occurrence of bass larger than 300 mm between the 1995 and 2009 surveys. The increasing size of largemouth bass is also apparent in the escalating average weight of trophy bass caught in the Delta (Figure 2-2). The average size of trophy bass has increased from approximately 5 to 5.5 pounds in the late 1980s and early 1990s to nearly 8 pounds in recent years.

The increase in both bass abundance and size in recent years reflects the favorable habitat conditions (e.g., increased SAV), particularly in the central and south Delta. For example, the data appear to show that the increased amount of SAV within the Delta has created more usable cover and foraging habitat for largemouth bass and sunfish (Conrad *et al.* 2010a and b, Conrad *et al.* 2011). The increase in predatory fish abundance in the Delta appears to be primarily largemouth bass and sunfish. The striped bass population has fluctuated in abundance over the past several decades, but there is no evidence that striped bass abundance has increased sufficiently in the past decade to account for the observed decline in juvenile salmon survival.

Largemouth bass and sunfish typically inhabit lakes and areas with abundant structural cover (e.g., docks, woody debris, SAV, etc.) where flows and water velocities are reduced. Water clarity in the Delta, particularly in the spring (Figure 2-4), has increased, presumably resulting from a decrease in sediment inflow to the Delta, the effects of SAV on settlement of fine sediment, and a reduction in sediment re-suspension. These conditions have resulted in improved conditions over the past decade for site-oriented visual predators, such as largemouth bass, that may have increased their predation efficiency.

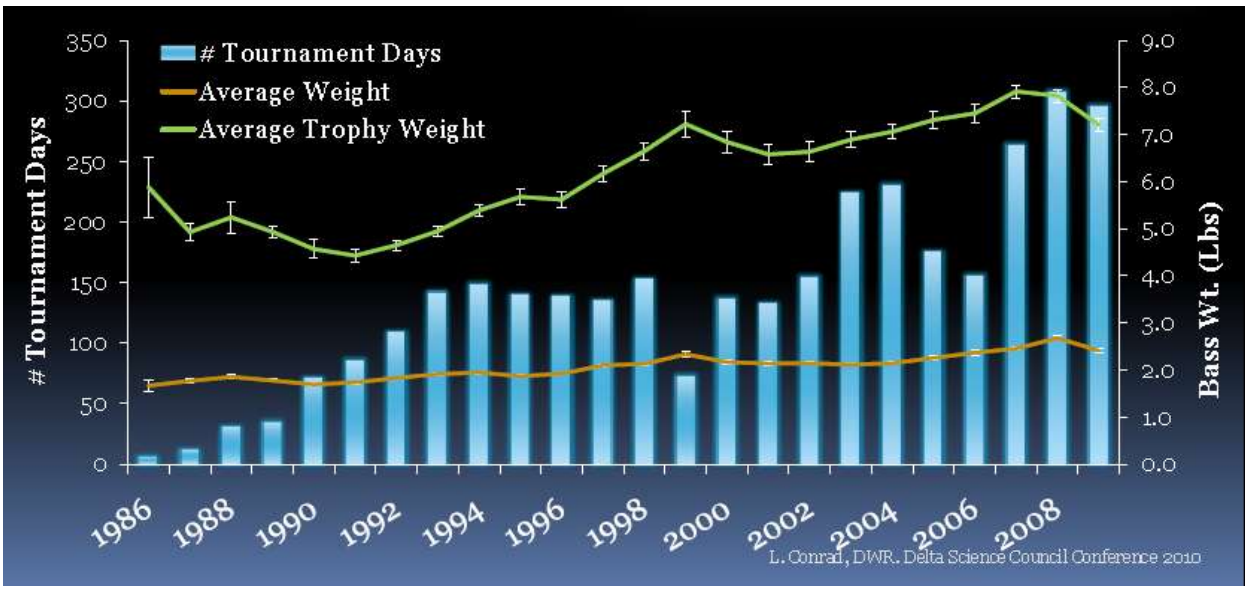

Figure 2-2. Number of largemouth bass tournament days in the Delta and trend in average weight of trophy bass (Source: Conrad *et al.* 2010b).

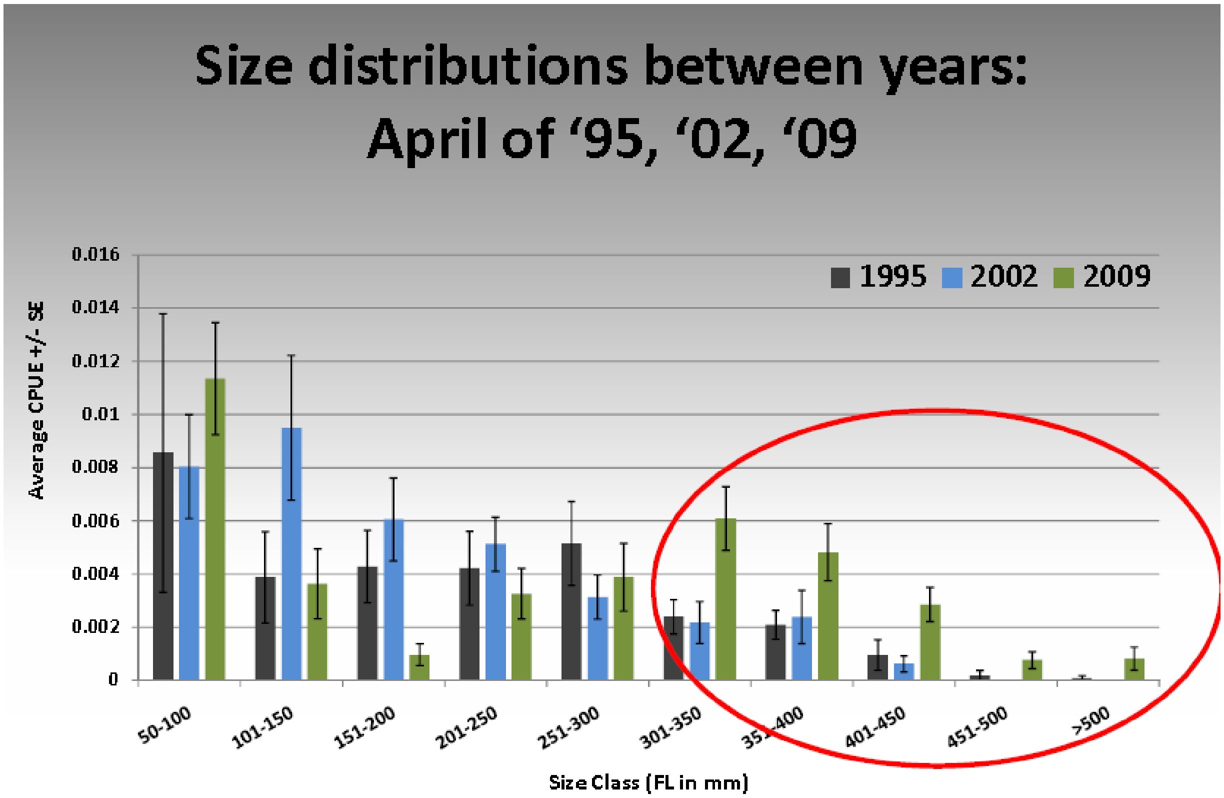

Figure 2-3. Length frequency trends in largemouth bass collected in the Delta (Source: Conrad *et al.* 2010a).

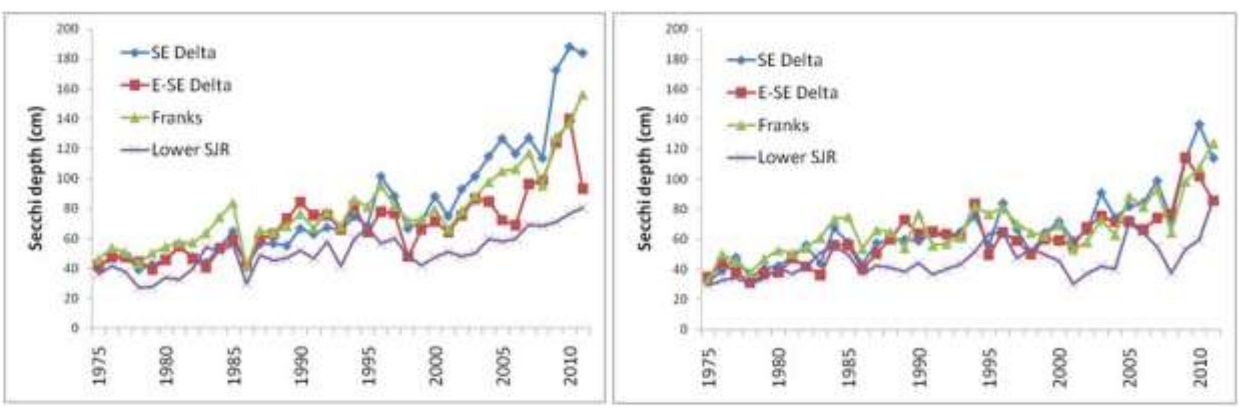

Figure 2-4. Changes in water clarity in the Delta over time as measured by Secchi depth. Left panel represents average March-June conditions and right panel represents average July – October conditions (Source: SWC/SLDMWA 2012).

It is well documented that larger bass prey primarily on crayfish and small fish (Conrad *et al.* 2010a), including salmonids. Largemouth and other bass, thus, represent a significant source of predation mortality for many of the forage fish inhabiting the Delta (e.g., juvenile Chinook salmon and steelhead, smelt, shad, and others).

The increasing non native bass and sunfish abundance trend has contributed to a change in the Delta fish community's species composition. Fishery survey data show a trend of increasing abundance of non-native fish inhabiting the Delta (Figure 2-5). During surveys in 1981-1982 native fish comprised 18 percent of the fish collected. In recent years, the relative contribution of native fish to the Delta community has declined to approximately 4 percent, as reflected in surveys in 2009-2010. By contrast, the relative contribution of bass and sunfish to the Delta fish community doubled from about 35 percent in 1981-1982 to about 74 percent in the 2009-2010 surveys Largemouth bass represented 35 percent of the fish collected in the most recent surveys.

There is mounting scientific evidence, including the increasing trend in the abundance and size of largemouth bass inhabiting the Delta and observations of declining survival of juvenile salmon, that over the past decade predation mortality by non-native fish has become a major factor adversely impacting the survival and abundance of juvenile Chinook salmon and other native fish in the Delta. Predation mortality by striped bass and largemouth bass has been identified as a major factor reducing the survival of juvenile salmon and steelhead entering Clifton Court Forebay (Gingras 1997, Clark *et al.* 2009), at fish salvage release sites (Miranda *et al.* 2010), and at other locations within the Central Valley rivers and Delta such as the Head of Old River (Bowen *et al.* 2009, Bowen and Bark 2010).

2.4 Recommendations

As shown in this section (and in Section 2), a wide range of environmental and biological factors affect habitat quality and availability, reproductive success, growth, and survival of Central Valley salmonids, in addition to the magnitude and seasonal timing of flows. NMFS, therefore, has recommended that when evaluating the potential effects of various management strategies, focus should be placed on the needs of each salmonid species across its entire lifecycle, and how any proposed management action may positively or adversely affect habitat suitability, growth, survival, movement, and the overall population dynamics of the species of interest (NMFS 2010a).

Given the complex habitat conditions in the Delta that provide cover for predatory fish and the hydrologic conditions in the Delta dominated by tidal flows rather than Delta inflows, increased or minimum Delta inflows or outflows are unlikely to have any effect on the abundance or distribution of either largemouth bass or sunfish in the Delta. Increased Delta inflow would not be expected to change the seasonal temperature conditions in the Delta or other elements of largemouth bass and sunfish habitat.

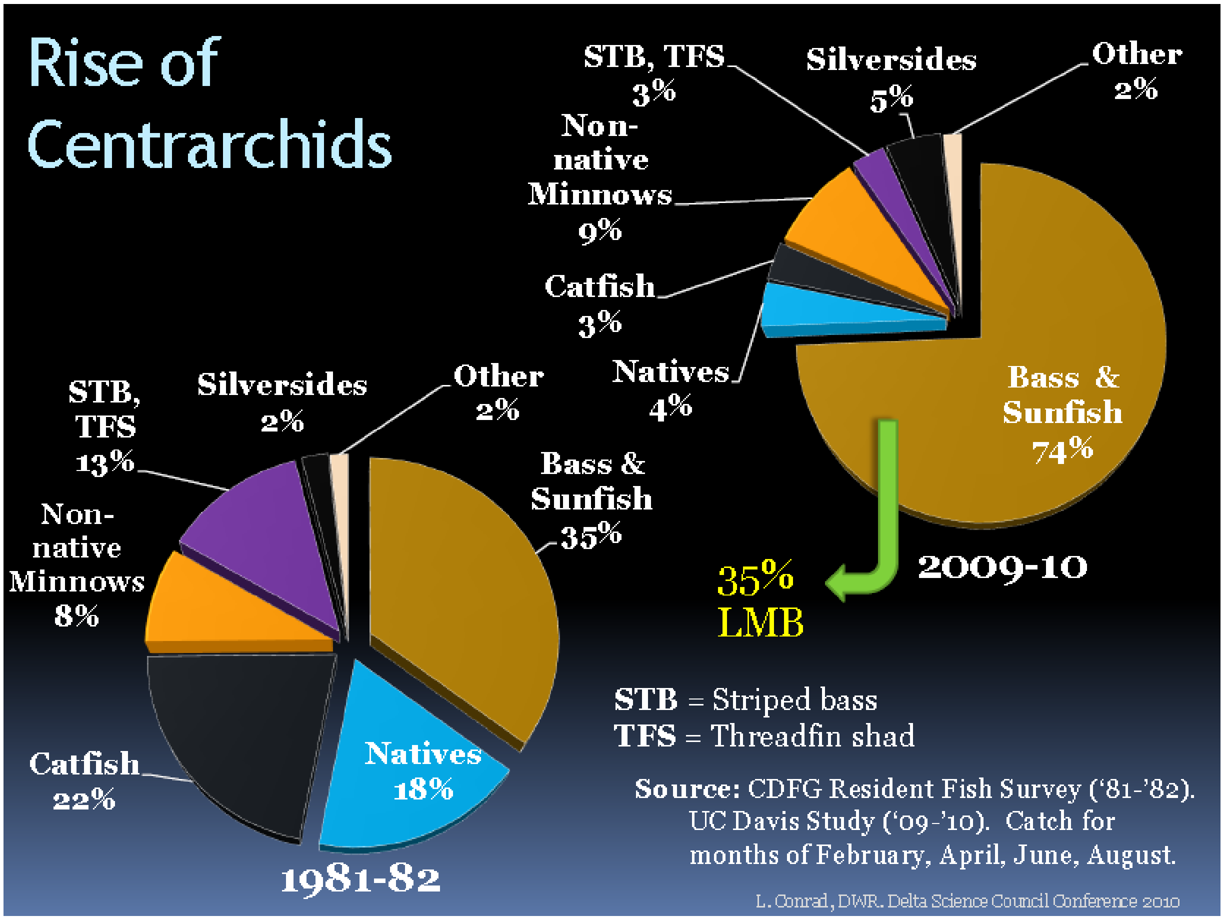

Figure 2-5. Change in fish species composition in surveys conducted in 1981-1982 and 2009-2010 (Source: Conrad *et al.* 2010 b).

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3 Existing Regulations Intended to Provide Protections and Habitat Enhancement

A number of regulatory requirements have been implemented to enhance and protect critical and essential habitat for Central Valley Chinook salmon, steelhead, and other aquatic resources within the Bay-Delta estuary and Central Valley rivers and tributaries. These regulations include, but are not limited to, actions by the State Water Resources Control Board, Central Valley and San Francisco Bay /Regional Water Quality Control Boards, NMFS, U.S. Bureau of Reclamation (Reclamation) Central Valley Project Improvement Act (CVPIA) requirements, California Department of Fish and Game (CDFG) agreements, Federal Energy Regulatory Commission (FERC) actions, Pacific Fisheries Management Council (PFMC) decisions, and other actions. (Table 3-1)

For example, SWRCB D-1641 limits SWP and CVP export rates during the salmon emigration period to not more than 65 percent of Delta inflow prior to February 1, and to not more than 35 percent of Delta inflow after February 1. D-1641 also requires that the Delta Cross Channel gates be closed beginning February 1 for the protection of juvenile emigrating salmon and steelhead and that the gates be closed for up to 45 days additional during the November through January period based on requests of the state and federal fishery agencies. In addition, the NMFS (2009) Long-Term Operational Criteria and Plan (OCAP) Biological Opinion limits direct losses of winter-run and spring-run Chinook salmon and steelhead as part of authorized levels of incidental take. These or similar take restrictions are expected to continue in effect until BDCP implementation is authorized.

Also, the Data Assessment Team (DAT), temperature task group and salmon decision tree management processes which currently provide a framework for assessing near real-time information on salmonid migration patterns, salvage, hydrodynamic conditions within the rivers and Delta for us in making adaptive management recommendations are expected to continue to protect and improve conditions for Central Valley salmonids.

In addition, over the past decade a significant number of habitat improvement and enhancement projects have been designed and implemented in Central Valley rivers and other aquatic habitats to benefit salmonids and other aquatic species as part of programs such as CALFED and the CVPIA Anadromous Fish Improvement Program.

Ongoing and completed actions have resulted in improvements to upstream and downstream fish passage, installation of state-of-the-art positive barrier fish screens on previously unscreened water diversions (e.g., Glenn-Colusa Irrigation District, RD108, RD1004, Sutter Mutual, and others), instream flow improvements, and physical habitat enhancement projects. The Red Bluff Diversion Dam (RBDD), which historically delayed or blocked salmonid migration to the Sacramento River’s upper reaches, is being replaced by a pumping plant and positive barrier fish screen. (Sacramento River Watershed Program 2012).

These and other projects benefit Central Valley Chinook salmon, steelhead, and their habitat through spawning gravel augmentation and habitat restoration, reduced risk of entrainment mortality through installation of fish screens on larger water diversion projects, and improved fish ladders and access to upstream spawning and rearing habitat provided by projects on Butte and Battle creeks, among others. Additional beneficial actions include improved access to seasonally inundated floodplains, channel margin habitat, tidal wetlands, hatchery management, harvest regulations and other actions to reduce stressors on salmonids.

Upstream enhancement projects are expected to continue throughout the interim period until BDCP implementation to improve salmonid habitat conditions and migration, and reduce and avoid entrainment losses at a numerous water diversion located along the Sacramento River by operating existing positive barrier fish screens. (BDCP is currently being developed as conservation actions intended to further reduce stressors on salmonids as well as improve habitat quality and availability.)

Ocean harvest restrictions intended to reduce adverse effects on Chinook salmon are also expected to remain in effect during the interim period.

Table B-1 in Attachment B summarizes many of the existing regulations and protections benefiting Central Valley salmonids and their habitat.

3.1 Considerations in Setting Future Regulatory Protections

Considering all stressors on salmonids and their habitats should influence the selection of appropriate management actions, including the determination of whether minimum instream flows or Delta outflows are appropriate. For example, delta smelt have a 1-year lifecycle, are limited in their distribution to the Delta, are subject to a wide variety of mortality sources, and have life history characteristics that increase their risk of jeopardy in response to short-term impacts. In contrast, species like Chinook salmon and steelhead live for 3 to 5 years or more, have multiple cohorts dispersed between freshwater and marine environments, have a wide geographic distribution, and have life history characteristics that reduce their risk of adverse impacts in response to short-term conditions (e.g., short drought conditions).

In assessing the risk of adverse impacts or benefits to salmonids at a population level resulting from a proposed management action or conservation actions, consideration should also be given to the duration of the action relative to the species' lifespan and life history. In addition, one should consider the potential magnitude of the action's effect on one or more lifestages, the geographic location of the potential effect relative to the distribution of all lifestages and population segments of the species, abundance of the species, including recent trends in cohort replacement rates, and the potential for cumulative impacts on the species. Applying lifecycle models and other analytic tools (Section 4) is key to effectively assess the potential for beneficial and adverse effects on salmonids in response to changes in water temperatures, habitat suitability for a given life stage in terms of water velocity and depth and other factors, access to suitable spawning and rearing habitat, and effects of river and tidal flows on survival during migration, harvest regulations, and other factors.

Table 3-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Shasta Division/Shasta & Keswick Dams	Sacramento River water temperature objectives	<56°F, April 1 – Sept. 30; <60 °F, Oct. 1 – 31 at Red Bluff Diversion Dam (RBDD)[1]	State Water Resources Control Board (SWRCB)
		< 56°F Keswick Dam to Bend Bridge with initial targets, based on May 1 Shasta cold water (<52°F) volume, as follows[2]: >3.6 MAF - Bend Bridge 3.3 - 3.6 MAF - Jellys Ferry <3.3 MAF - Balls Ferry	National Marine Fisheries Service (NMFS)
	Sacramento River Temperature Task Group (SRTTG)[3]	Convened to formulate, monitor & coordinate annual temperature control plans	SWRCB
	Shasta Reservoir target minimum end of year carry-over storage (1.9 MAF)	To increase probability that sufficient cold water pool will be available to maintain suitable Sacramento River water temperatures for winter-run Chinook the following year	NMFS
	Sacramento River flows (releases from Keswick Dam)	Minimum flows: 3,250 cfs October 1 – March 30	SWRCB, CVPIA
	Flow ramp down rates from Shasta Dam	Apply following schedule between July 1 and March 31[4]: • Reduce flows sunset to sunrise only • ≥6,000 cfs; < 15%/night and 2.5%/hour • 4,000 to 5,999 cfs; <200 cfs/night and 100 cfs/hour • 3,250 to 3,999 cfs; <100 cfs/night	NMFS
Red Bluff Diversion Dam	Gate operations	Gates raised from September 15 to May 14[5]	NMFS
	Sacramento River Water temperature objectives	<56°F, April 1 – Sept. 30; <60 °F, Oct. 1 – 31	SWRCB

1 Allows flexibility when water temperatures cannot be met at RBDD. Temperature management plan developed each year by the Sacramento River Temperature Task Group (SRTTG).

2 Based on temperature management plan developed annually by the SRTTG.

3 The SRTTG is composed of representatives of SWRCB, NMFS, FWS, DFG, Reclamation, WAPA, DWR & Hoopa tribe.

4 Variations to ramping rate schedule allowed under flood control operations

5 Provides flexibility to temporarily allow intermittent gate closures (up to ten days, one time per year) to be approved on a case-by-case basis to meet critical diversion needs. Reclamation will reopen the gates for a minimum of five consecutive days, prior to June 15 of the same year in a manner that will be least likely to adversely affect water deliveries.

Table 3-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Wilkins Slough	Navigation Flow Objective	Minimum of 5,000 cfs at Wilkins Slough gauging station on the Sacramento River; can relax standard to 3,500 cfs for short periods in critical dry years[6]	USBR
Oroville/Feather River Operations	Feather River minimum flows	600 cfs below Thermalito Diversion Dam when Lake Oroville elevation <733 ft MSL increasing to 1,000 cfs April through September if Lake Oroville elevation >733 ft MSL; Flows generals kept < 2,500 cfs August through April to avoid stranding salmonids	DWR & DFG Agreement
American River Division/Folsom & Nimbus Dams	American River minimum flow standards	Minimum 250 cfs January 1 to September 14 & 500 cfs September 15 to December 31 measured at the mouth of American River	SWRCB
	American River temperature objectives	Reclamation to develop, in coordination with the American River Operations Group and NMFS, annual water temperature control plan to target 68°F at Watt Avenue Bridge	NMFS
Eastside Division	Support of San Joaquin River requirements and objectives at Vernalis	Vernalis flow requirements February to June, Vernalis water quality objectives	SWRCB
New Melones Dam & Reservoir Operations	Flows for fish & wildlife; dissolved oxygen standards at Ripon	Release a minimum of 98,000 acre-feet of water to lower Stanislaus River below Goodwin dam	SWRCB & DFG
Delta Cross Channel	Gate Closures	Gates closed February through May, 14 days May 21 to June 15, 45 days November 1 to January 1 to protect Sacramento River salmonids	SWRCB
Tracy & Banks Pumping Plants	Pumping Curtailments	Protect listed salmonids; meet export/Inflow ratio, X2, delta outflow requirements	SWRCB; NMFS

[6] While commercial navigation no longer occurs between Sacramento and Chico Landing, long-term water users diverting from the river have set their pump intakes just below a minimum flow requirement of 5,000 cfs at Wilkins Slough. Diverters are able to operate for extended periods at flows as low as 4,000 cfs at Wilkins Slough; pumping operations become severely affected and some pumps become inoperable at flow less than 4,000 cfs. While no criteria have been established for critically dry years, the standard can be relaxed to a minimum flow of 3,500 cfs for short periods to conserve water storage in Shasta Reservoir and manage for multiple project and environmental objectives.

Table 3-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Contra Costa Canal operations	Diversion rate limits, fish screens	Protect listed salmonids	NMFS
Ocean Salmon Harvest	All California ocean commercial and sport salmon fisheries are currently managed by PFMC harvest regulations	Conservation Objective = 122,000 to 180,000 natural and hatchery Sacramento River Fall Run Chinook (SRFC) salmon spawners[7] Ocean commercial and recreational harvest in the ocean was banned in 2008 and 2009	NMFS, California Fish and Game Commission, Pacific Fishery Management Council
Inland Salmon Harvest	Zero bag limit on the American River, Auburn Ravine Creek, Bear River, Coon Creek, Dry Creek, Feather River, Merced River, Mokelumne River, Napa River, San Joaquin River, Stanislaus River, Tuolumne River, Yuba River, and the Sacramento River except for a one salmon bag limit in the Sacramento River from Red Bluff Diversion Dam to Knights Landing from November 1 to December 31.	To protect fall-run Chinook salmon stocks starting in 2008	California Fish and Game Commission

[7] The conservation objective has been set by the Pacific Fishery Management Council in the Salmon Fishery Management Plan.

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4 Lifecycle Modeling and other Analytical Tools

4.1 Introduction

Analytical tools are available that can be used to evaluate the predicted benefits of various management actions on salmonids' population dynamics and survival. These tools assess the relative contribution of various stressors to salmonid species. These tools allow comparative cost/benefit assessments for management actions. These tools can also be used to assess the relative importance of a stressor on the overall species' population dynamics and provide a framework for identifying and evaluating potential management actions.

Following is a brief discussion of available lifecycle modeling and analytical tools. A more detailed discussion of these tools will be submitted by SWC/SLDMWA in conjunction with the State Board's November 2012 Analytical Tools Workshop.

Lifecycle modeling can play a powerful role in evaluating the interrelationships among individual factors that give rise to broad patterns in population dynamics. Understanding the processes that produce such patterns is key to developing management principles (Levin 1992). Ruckelshaus *et al.* (2002) conclude that using better models in making management decisions is one obvious way to change how risks to salmon populations are managed.

Multiple efforts have been undertaken to develop effective models for Central Valley salmon. Williams (2006) classifies these models into two general categories: estimation models, which estimate parameter values by directly fitting the model to available data; and simulation models, which take parameter values from literature or other sources. An example of an estimation model is the Bayesian hierarchical state-space model developed by Newman and Lindley (2006), which incorporates multiple data sources to roughly predict juvenile out-migration based on data for juveniles from the preceding year. An example of a simulation model is the SALMOD model (Bartholow *et al.* 1997 Bartholow 2004), which combines information regarding run timing with fine-scale data regarding spatial and temporal variations in flow and temperature to define computational units which are then used to assess the effects of river flow and water temperatures on the production of Chinook salmon in the upper Sacramento River.

While the results of these earlier models have provided valuable insights, their narrow focus and limited geographic area reduce their utility in assessing the relative impact on overall population viability of actions at specific locations and affecting specific salmonid life stages (Rose *et al.* 2011, Zeug *et al.* 2012). A framework is needed for organizing the body of information regarding the impact of changes in environmental variables (e.g., flow, temperature, exports, harvest, and physical habitat), for quantifying the effects of these changes on the abundance of salmon at each life stage (e.g., development, migration, and maturation), and for evaluating the resulting impact on overall population viability. Lifecycle models provide such a framework. Both scientists and managers have increasingly recognized the utility of lifecycle models for evaluating salmon population responses to management actions (Ruckelshaus *et al.* 2002), and a recent review of salmon recovery efforts in California's Central Valley recommended their use (Good *et al.* 2007).

4.2 IOS Lifecycle Model

The Interactive Object-oriented Simulation (IOS) model has undergone extensive development and interagency review and is currently the only Central Valley Chinook salmon lifecycle model that has been published in the peer reviewed scientific literature (Zeug *et al.* 2012) and that has been specifically designed to incorporate life stages, geographic areas, and influencing factors at a scale closely matching those affected by alternative water management actions. The model was developed by Cramer Fish Sciences to simulate the interaction of environmental variables with all life stages of winter-run Chinook salmon in the Sacramento River, Sacramento-San Joaquin Delta, and Pacific Ocean. Fish behaviors modeled by IOS include emergence (eggs to fry), rearing, migration, and maturation (ocean phase). The IOS model dynamically simulates responses of salmon populations across these model-stages to changes in environmental variables or combinations of environmental variables in the geographical areas specified for each model-stage, and enables scientists and managers to investigate the relative importance of specific environmental variables by varying a parameter of interest while holding others constant; an approach similar to the testing of variables in a laboratory setting. The IOS lifecycle model estimates adult escapement, which is the primary key to population viability over time.

Figure 4-1 shows a map of the Sacramento River and Delta and the approximate geographic distribution of salmonid lifestages included in the IOS model.

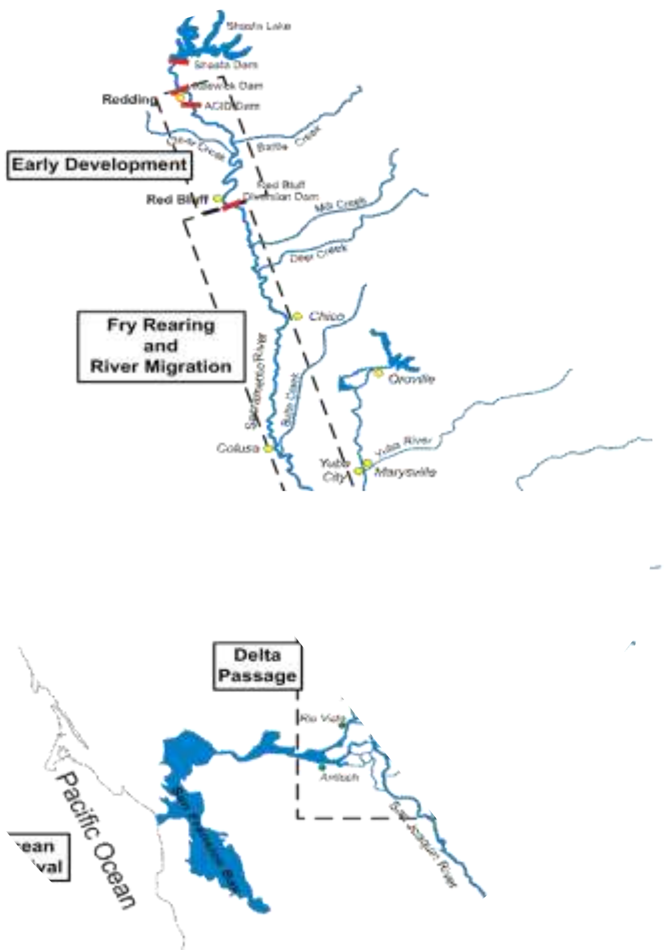

Figure 4-1. Map of the Sacramento River and the Sacramento-San Joaquin Delta, including approximate areas defined by model-stages.

4.3 Delta Passage Model

The Delta Passage Model (DPM) is a stochastic simulation model developed by Cramer Fish Sciences to evaluate the water management actions' impacts and conservation measures on the survival of Chinook salmon smolts as they migrate through the Delta. The DPM is not a lifecycle model, but is incorporated as a sub-model in the IOS lifecycle model (described above), comprising the *Delta Passage* model-stage. A detailed DPM description is included in the peer reviewed IOS lifecycle model paper (Zeug *et al.* 2012). The DPM is also used as a stand-alone model to analyze Delta survival and routing.

The DPM simulates juvenile Chinook salmon smolt migration as they enter the Delta from the Sacramento River, Mokelumne River, and San Joaquin River, and estimates survival through the Delta to Chipps Island. The DPM comprises eight reaches and four junctions (Figure 4-2) selected to represent the primary salmonid migration corridors where fish and hydrodynamic data are available. The model can also provide survival estimates for specific reaches or life stages. The DPM can be used to inform which management actions likely have the most benefit for improving smolt survival, as well as locations in the Delta where such actions are likely to have the most benefit—a level of detail which aggregated estimates of survival through the Delta cannot provide. DPM model development has been made possible by the results of acoustic tagging studies, which have demonstrated repeatable migration routing patterns at junctions as well as different survival rates among routes.

The DPM uses the best available empirical data to parameterize model relationships and inform uncertainty, thereby utilizing the greatest amount of data available to dynamically simulate responses of smolt survival to changes in model inputs or parameters in the model. Figure 4-3 shows an example of the best available data used in the model. The DPM is primarily based on Sacramento Basin studies of late fall-run and San Joaquin basin studies of fall-run Chinook, but it has been applied to winter-run, spring-run, late fall-run, Sacramento fall-run, Mokelumne River fall-run, and San Joaquin fall-run Chinook salmon by adjusting emigration timing and by assuming that all migrating Chinook salmon smolts respond similarly to Delta conditions.

Although studies have shown considerable variation in emigrant size, with Central Valley Chinook salmon migrating as fry, parr, or smolts (Brandes and McLain 2001; Williams 2006), the DPM relies predominantly on data from acoustic tagging studies of large (>140 mm) smolts. Unfortunately, survival data is limited for small (fry-sized) juvenile emigrants due to the difficulty of tagging such small individuals. Therefore, the DPM should be viewed as a smolt survival model only, most applicable to large smolts (>140 mm), with the fate of pre-smolt emigrants not incorporated in the model.

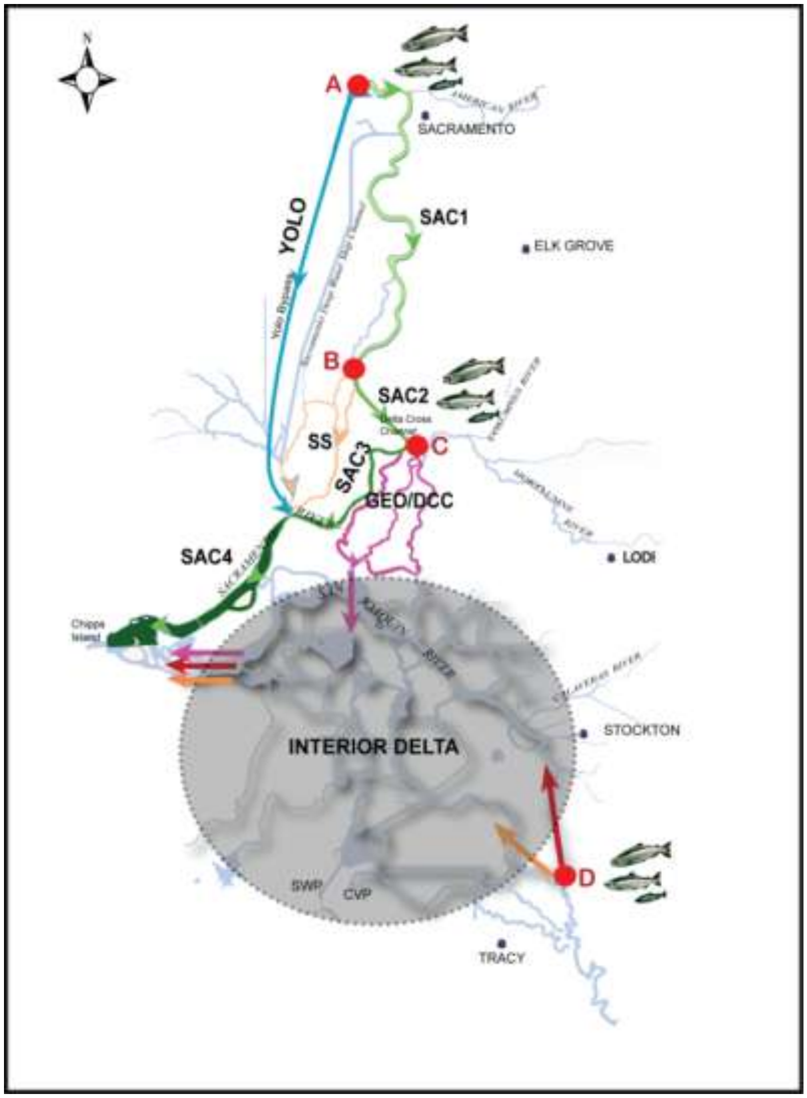

Figure 4-2. Map of the Sacramento-San Joaquin Delta showing the modeled reaches and junctions of the Delta applied in the DPM. Bold headings label modeled reaches and red circles indicate model junctions. Salmon icons indicate locations where smolts enter the Delta in the DPM.

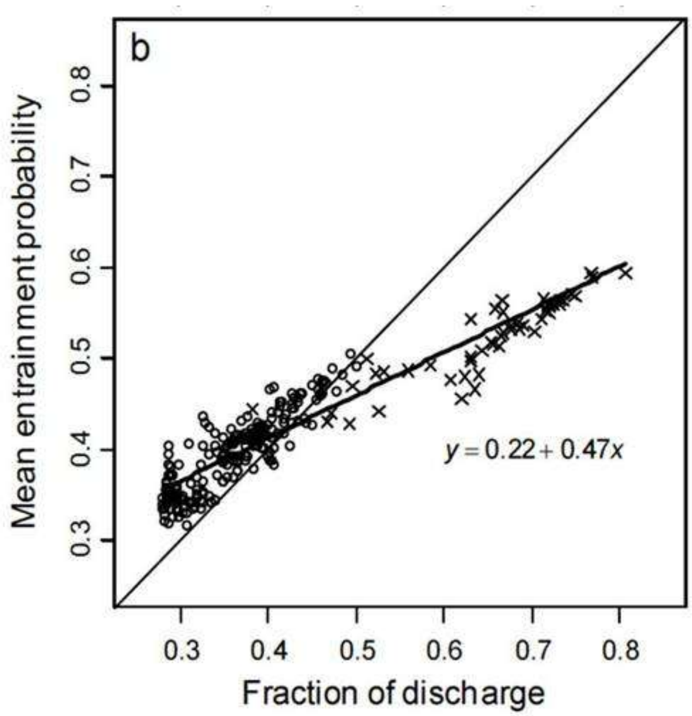

Figure 4-3. Figure from Perry (2010) depicting the mean entrainment probability (proportion of fish being diverted into reach Geo/DCC) as a function of fraction of discharge (proportion of flow entering reach Geo/DCC). In the DPM, this linear function is applied to predict the daily proportion of fish movement into Geo/DCC as a function of the proportion of flow movement into Geo/DCC. A circle indicates when the DCC gates were closed and X indicates when the DCC gates were open.

4.4 SALMOD Model

SALMOD simulates how habitat changes affect freshwater salmon population dynamics (Bartholow *et al.* 1997, Bartholow 2004). It was developed to link fish production with flow, as described by the Physical Habitat Simulation System (PHABSIM) model. SALMOD was used in the Biological Assessment (BA) for the National Marine Fisheries Service 2009 Salmon BiOp (USBR 2008), and is described in the BA as follows:

> "SALMOD simulates population dynamics for all four runs of Chinook salmon in the Sacramento River between Keswick Dam and RBDD. SALMOD presupposes egg and fish mortality are directly related to spatially and temporally variable microhabitat and macrohabitat limitations, which themselves are related to the timing and volume of streamflow and other meteorological variables. SALMOD is a spatially explicit model in which habitat quality and carrying capacity are characterized by the hydraulic and thermal properties of individual mesohabitats, which serve as spatial computation units in the model. The model tracks a population of spatially distinct cohorts that originate as eggs and grow from one life stage to another as a function of water temperature in a computational unit. Individual cohorts either remain in the computational unit in which they emerged or move, in whole or in part, to nearby units. Model processes include spawning (with redd superimposition), incubation losses (from either redd scouring or dewatering), growth (including egg maturation), mortality due to water temperature and other causes, and movement (habitat and seasonally induced). SALMOD is organized around physical and environmental events on a weekly basis occurring during a fish's

> biological year (also termed a brood year), beginning with adult holding and typically concluding with fish that are physiologically "ready" to begin migration towards the ocean. Input variables, represented as weekly average values, include streamflow, water temperature, and number and distribution of adult spawners" (USBR 2008, p.9-25).

SALMOD does not simulate the influence of environmental variables on salmonid population dynamics during the river migration, Delta migration, or ocean maturation phases of the salmonid life cycle. Thus, SALMOD is not used to estimate adult escapement; the primary key to population viability over time. The life stages and geographic areas addressed by SALMOD are contained and described in the IOS lifecycle model using similar functional relationships.

4.5 OBAN Model

The Oncorhynchus Bayesian Analysis (OBAN) is a statistical model developed by Hendrix (2008) and used to quantify uncertainties in potential outcomes and long-term population viability due to variations in environmental conditions, but not to compare population effects at the spatial and temporal scale of specific management actions. OBAN is described in a recent NMFS review of salmon lifecycle models (NMFS 2012) as follows:

> OBAN is a statistical life cycle model that includes life stages based on a Beverton-Holt function. OBAN defines the transformation from one life stage to the next in terms of survival and carrying capacity. Unlike the mechanistic models, it does not consider the timing of movement between stages or habitats. Additionally, the survival and carrying capacity parameters are determined by a set of time varying covariates. There is no specific mechanistic relationship between the parameters and the survival and carrying capacity. The weighting terms for the influence of environmental covariates on the Beverton-Holt functions are established by fitting the model to spawner recruit data. (NMFS 2012, p.5).

Unlike the IOS lifecycle model, OBAN does not compare population effects at the spatial and temporal scale of specific management actions. Also, the OBAN model has not been published in a peer reviewed scientific journal, and no detailed description of model relationships or coefficients is currently available.

4.6 NMFS Lifecycle Model

NMFS has recently proposed developing a new lifecycle model for Central Valley salmonids. After holding a June 2011 Independent Panel Workshop in which existing lifecycle models were reviewed (Rose *et al.* 2011), NMFS concluded that none of the existing models was sufficiently well suited for use in supporting the OCAP and BDCP Biological Opinions. An important consideration in this decision was the perceived need for complete ownership and control of the model (NMFS 2012). To that end, NMFS proposed the development of its own lifecycle model for winter-run Chinook. The proposal was completed in February 2012 and conveyed to Reclamation and the California Department of Water Resources (DWR) in March 2012. The initial model is to be completed and available for use by NMFS to evaluate OCAP Reasonable and Prudent Alternatives (RPAs) by December 2013. NMFS' approach to the new lifecycle model is summarized in the proposal as follows:

> The NMFS lifecycle model needs to be able to translate the effects of detailed water project operations into population effects. There are at least two ways this might be approached: (1) a brand-new coupled physical and individual-based biological simulation model or (2) linking existing physical models to a population-level stage-structured lifecycle model through state-transition parameters that are a function of the environment (as described by the physical models). We are pursuing the latter strategy because we

> are more certain it will yield useful products in time for the OCAP and BDCP processes, and because it will be easier to analyze, understand and explain model outputs.
>
> Our work will proceed on four fronts—development and refinement of the lifecycle modeling framework; application, improvement and integration of physical models; development of linkages between physical model outputs and stage-transition parameters; and assembly of data sets needed to determine the physical-biological couplings and assess overall model performance. Periodically, we will integrate work in these four areas to produce assessment tools ("lifecycle models") that can address increasingly complex management scenarios. Along the way, we will work with interested parties (especially agency staff responsible for the Biological Opinions) to guide development, through periodical workshops and webinars. We will deliver working models, analyses of select scenarios, documentation, and peer-reviewed publications (NMFS 2012, p.3).

At this time, the NMFS lifecycle model is under development; the lifecycle model is at least a year or more from completion. As a result, the use of available models such as IOS is necessary for the current evaluation and planning of management actions, and to provide important feedback for the development and use of future models such as the NMFS lifecycle model.

4.7 Recommendations

Central Valley salmonids have a complex and diverse life history. Many factors affect the species' reproductive success, growth, health, survival, and abundance. Lifecycle models provide a tool for assessing the relative importance of various factors on the abundance of adults as reflected through beneficial and adverse effects of stressors at each life stage. Lifecycle models for salmonids have been developed for use in evaluating the predicted effects of alternative management actions and climate change on the population dynamics of salmon in the Pacific Northwest and elsewhere (Scheuerell *et al.* undated, Rivot *et al.* 2004, Crozier *et al.* 2008, Kope *et al.* undated, Noble *et al.* 2009). These models provide an analytical framework for applying the best available scientific information to determine a given life stage response to a management action or environmental condition. Lifecycle models can also help identify future monitoring and necessary experiments to improve model assumptions and functional relationships. Advanced modeling tools currently exist, and additional tools are being developed and refined, that can and should be applied to the effects analysis of any proposed management actions on the population dynamics of Central Valley salmonids.

The State Board should thoroughly and carefully apply the best available scientific tools when it evaluates the potential efficacy of proposed management actions under consideration, including flow requirements.

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5 The Biological Effects on Salmonids of a Natural Flow Regime in the Sacramento River

The State Water Board's 2010 Flow Criteria Report (SWRCB 2010) identifies a percentage of natural (unimpaired) flows as an approach to improving conditions for salmonids and other aquatic resources in the Bay-Delta estuary. This section discusses historic conditions related to flows, current conditions, and the modeled impacts of a natural or unimpaired flow approach on salmonids.

We incorporate by reference the discussion in Section 6 (pp. 6-1 to 6-8) of the SWC/SLDMWA written comments submitted for Workshop 1. In brief, those comments explain the differences between unimpaired flows and natural flow, confirm that variability in flows in the post-Project period is generally greater than pre-Projects, describe the biological functions of natural flows (including the findings that flow regimes typically confound other environmental factors), that the relationship between flows and species abundance is generally subject to significant uncertainty, particularly in estuaries, and that reservoir releases cannot restore the functionality of the highly altered Delta. Reservoir releases typically have relatively low turbidity and do not provide the functions that natural stormwater runoff from a watershed served in providing a range of flow, temperature, and turbidity cues that stimulate salmonid migration and other processes.

5.1 Natural Flow: Historical Context

Historically, Central Valley salmonids evolved and adapted to natural flow conditions and the associated changes in seasonal water temperatures that would potentially affect each life stage. Winter-run Chinook salmon that hold as adults in rivers during the late winter, spring, and summer months prior to spawning had access to high elevation habitats in the upper reaches of the watershed where water temperatures were cool throughout the year. These upper watershed areas provided suitable habitat for holding adults, spawning, egg incubation, and juvenile rearing (Williams 2006).

Steelhead and spring-run Chinook salmon also accessed high elevation habitat prior to the construction of the major rim dams. Fall-run Chinook salmon migrated upstream later in the fall when seasonal water temperatures were declining. Spawning and egg incubation occurred, and continues to occur, during the late fall and winter when temperatures are naturally cool. These lower temperatures also provided suitable habitat further downstream at lower elevations in the valley floor. As a result of construction of major rim dams such as Shasta and Keswick, winter-run, other salmon runs and steelhead no longer have access to suitable habitat located in the upper reaches of the Central Valley watershed. Instead, the species are now restricted to lower elevation valley floor habitat where suitable water temperature conditions are maintained through reservoir storage and management to provide seasonal cold water releases to meet the temperature requirements of these species through their freshwater life stages.

From a habitat perspective, in Central Valley rivers such as the Sacramento, Feather, American, Mokelumne, Merced, Tuolumne, and Stanislaus rivers, major habitat modifications occurred as a result of dam construction for flood control and water supply. Farther downstream in the Sacramento and San Joaquin river channels, modifications in the form of levee construction, channelization, and bank protection using rip-rap has further altered habitat conditions and affected how salmonids respond to changes in flow. For example, historically, increased streamflow in response to natural runoff during the winter and spring months resulted in seasonal inundation of shallow channel margin habitat, floodplain, and tidal wetlands (Figure 5-1). These areas provided juvenile salmonids with rearing habitat, cover and protection from predators, and increased food resources. These habitat functions are now mostly lost or substantially diminished for Central Valley salmonids. Figure 5-2 shows a cross section through a channelized and leveed reach of the Sacramento River where a substantial increase in river flow (e.g., an increase of 10,000 cfs in this example) results in a very minimal increase in the quality or availability of suitable habitat for juvenile rearing or migrating salmon or steelhead. Habitat modification is therefore a major factor to consider when evaluating unimpaired flow effects on management strategies for Central Valley salmonids.

5.1.1 Current Conditions, with a Focus on Coldwater Pool Management and Winter-Run

Winter-run Chinook salmon currently have a single population that relies on the upper Sacramento River immediately downstream of Keswick Dam for adult holding, spawning and egg incubation, and for juvenile rearing habitat. With only one population, winter-run salmon have an increased risk of adverse population effects (e.g., jeopardy of extinction) when compared to species with multiple independent viable populations that are geographically dispersed throughout Central Valley rivers. High mortality of pre-spawning-adults, incubating eggs, or rearing juveniles in any given year has the potential to eliminate one complete year class from the winter-run salmon population. The loss of all or a major part of one year class of winter-run salmon will adversely impact recovery of the species, as illustrated by the decline in adult abundance observed in 2007 in response to poor ocean-rearing conditions. The depletion of reservoir storage and coldwater pool volumes during the summer has potential adverse effects on winter-run, not only in the first year, but also for carryover storage in following years, particularly if conditions are dry in those following years. Thus, depletion of coldwater pool volumes in one year could be disastrous for winter-run abundance and upstream habitat, particularly if the following year is dry.

Adult winter-run salmon spawn in the Sacramento River during the summer months when air temperatures in the Redding area are typically hot. Spawning and egg incubation continue to occur through the summer months. Salmon eggs are the most thermally sensitive lifestage, with exposure to water temperatures above 57 F (13.9 C) resulting in a rapid increase in egg mortality (Boles 1988). Management of reservoir storage and coldwater within Shasta Reservoir represents a major factor affecting the hatching success and subsequent abundance of winter-run Chinook salmon (NMFS 2010a). In the event that coldwater is depleted from Shasta Reservoir prior to fry emergence, mortality would be expected to increase rapidly as water temperatures increase above 57 F (BDCP 2010, NMFS 2010a, Williams 2006).

Under current regulation, reservoir storage is actively managed to maintain coldwater for release during the summer to meet the temperature requirements for incubating winter-run salmon eggs (see Section 3). Even under current coldwater pool management and release conditions, the hydrology regime needed to support salmonid spawning and rearing in the upper watershed has sometimes proven difficult to achieve despite active modifications to the management strategy on a near real-time basis during the summer and fall months.

5.1.2 Assessing the Potential Biological Effects on Salmonids of Alternative Natural Flow Management

The SWRCB (2010) and others have expressed interest in developing alternative flow management strategies intended to benefit Central Valley salmonids and other aquatic resources. Mimicking natural flow patterns has been proposed by several investigators as a method for maintaining flow functions for fishery habitat (Poff *et al.* 1997, Richter *et al.* 1996, Poff and Zimmerman (2010). Altering the instream flow releases from upstream reservoirs to mimic natural flow regimes, however, has the potential to result in adverse effects on fish and their habitat. Assessing the effects of modifications to flow regimes on various fishery resources requires consideration of changes in hydrologic conditions (instream flows, ramping and potential for dewatering and stranding) as well as changes in reservoir storage and coldwater pool available to meet downstream temperature requirements for salmonid adult holding, spawning and egg incubation, juvenile rearing, and migration. Experience gained over the past decade in assessing potential habitat changes for proposed projects such as BDCP have resulted in development and refinement of a variety of analytical tools that will be the subject of discussion in Workshop 3.

Preliminary hydrologic modeling of potential changes in upstream reservoir storage and instream flows has been performed by MBK Engineers (2011), Water and Power Policy Group 2012, and HDR *et al.* 2011. Preliminary results suggest that there is a potential to substantially alter reservoir storage dynamics and instream flows through altered flow regimes that would adversely affect salmonids. Results of these analyses show that reservoir storage at Shasta, Oroville, Trinity and Folsom Reservoirs may be substantially impacted by winter and spring releases under the unimpaired flow conditions when compared to current operations. The average change in carryover storage and the percentage of years when the storage at each of the four reservoirs would be at dead pool under the three unimpaired flow regimes examined in these analyses would significantly increase.

Reductions in coldwater pool storage and the increased frequency of reservoirs reaching dead pool—in some cases potentially over a number of consecutive years--would expose salmonids to elevated water temperatures, reduce instream flow and physical habitat, likely lead to high mortality and stress for salmonids inhabiting areas downstream of each of the dams, and ultimately reduce population abundance and increase the species' risk of extinction. These conditions would be expected to adversely affect winter-run, spring-run, fall-run, and late fall-run Chinook and steelhead downstream of Shasta and Keswick dams, spring-run and fall-run Chinook and steelhead on the Feather River, fall-run Chinook and steelhead on the American River, and all salmonids inhabiting the Trinity River.

Impacts would also be expected for coldwater resident fish such as rainbow trout downstream of the dams. As a result depleting reservoir storage, impacts would also be expected to habitat and abundance of resident fish such as bass, crappie, bluegill, catfish, kokanee, and trout that inhabit upstream reservoirs. Additional application of hydrologic simulation models, in combination with water temperature modeling and salmonid population modeling (e.g., SALMOD, DPM, IOS), would be required to fully and quantitatively evaluate the frequency, magnitude, and population benefits and impacts of these conditions to each of the salmonids inhabiting Central Valley rivers.

Future changes in climate that result in greater seasonal air temperatures would make the expected adverse impacts of higher water temperatures even more severe on salmonids This could conceivably lead to a greater risk of adverse population level impacts on salmonid spawning, egg incubation, juvenile rearing, and adult holding in reaches of Central Valley rivers under the unimpaired flow regime than predicted in these analyses and contribute to a substantial increase in the risk of significant adverse impacts to salmonids in the future when compared to current reservoir and instream flow operations.

Further, high releases of flow under the unimpaired flow strategy during the winter and spring months would not only deplete reservoir storage and coldwater pool volumes, it would also lead to significant reductions in instream flows later in the summer, and during the fall and early winter. That is, releasing higher volumes of stored water in the winter, spring, and early summer months not only reduces coldwater storage, it also depletes the volumes of water available for release in later months. The resulting reduced river flows in the fall and early winter months—before the precipitation season ordinarily brings more water to the system—would further contribute to reduced salmonid habitat quality and availability for those lifestages that over-summer in the upper reaches of the river, such as rearing juvenile steelhead.

Reduction in instream flows in the summer and fall would reduce habitat quality and availability (reduced water depth and velocity) for pre-spawning adult winter-run and spring-run Chinook salmon holding in the Sacramento River downstream of Shasta and Keswick dams, as well as for pre-spawning holding habitat for spring-run salmon adults on the Feather and Trinity rivers. Reduced flows in the fall months

(September – December) would adversely impact habitat and temperatures for fall-run Chinook salmon spawning and egg incubation on the Sacramento, Feather, American, and Trinity rivers. Reduced summer and fall flows would also be expected to impact habitat and seasonal water temperatures for oversummering juvenile steelhead on the Sacramento, Feather, American, and Trinity rivers. A reduction in summer and fall flows would also impact habitat conditions in the rivers for resident rainbow trout and other fish species.

Flow reduction in the summer and fall months would not only impact physical habitat conditions (wetted cross section, water depths and velocities) for salmonids, it would also further exacerbate species exposure to elevated water temperatures later in the summer and fall months when juvenile lifestages of salmon and steelhead are present in the rivers. Although increased river flows in the winter and spring under the unimpaired flow strategy may provide benefits to some species and lifestages for fish (e.g., juvenile salmon and steelhead migration in the winter and spring, Delta outflows for pelagic species further downstream in the estuary), increased flow releases and depletion of coldwater pool storage and reduction in stream flow during the summer and fall months would result in adverse impacts to other salmonid species, including the increased potential for high mortality of all naturally-reproducing salmon and steelhead populations inhabiting the Sacramento River basin and a high risk of extinction of winter-run Chinook salmon that currently only inhabit the Sacramento River mainstem.

These preliminary model analyses regarding potential impacts to coldwater pool volumes, as well as the effects analyses for BDCP and other potential water project operations, illustrate the value of using models such as CALSIM to examine expected changes in flows and reservoir operations that could occur under an altered hydrologic regime. These hydrologic models can be used to examine changes in reservoir storage, the effects of changes in carryover storage over multiple years, and changes in river flows over wide ranging conditions. Hydrologic model results can then be integrated with water temperature simulation modeling to determine seasonal changes in the water temperature conditions at various locations downstream of major dams. Water temperature modeling results then provide the input for assessing changes in salmonid egg mortality (e.g., USBR egg mortality model) and rearing habitat for juvenile salmonids (e.g., SALMOD). Results of these models also provide input for juvenile survival models (DPM) and for lifecycle models (e.g., IOS) that can be used to further assess potential effects of a change in flow regimes on salmonid habitat and population dynamics. These models can also be modified to assess the potential incremental and cumulative effects of future climate change scenarios on Central Valley salmonids.

Given the potential for modifications to Sacramento River winter – spring flows to adversely impact upstream habitat for all species of Central Valley salmonids, resident coldwater species, and species inhabiting the reservoirs, detailed qualitative analysis of potential adverse impacts to salmonids is required as part of the evaluation of any proposed increased flow regime. Operation conditions effects on the expected survival, reproduction, abundance, and risk of extinction for all Central Valley salmonids must be examined in detail.

Given the anticipated adverse outcomes to salmonids associated with increasing releases and reducing coldwater pool volumes, we believe a management option other than a rigid increased flow strategy is required. A conservative approach should be established to protect the greatest number of winter-run eggs and subsequent habitat conditions for juvenile winter-run. Spring-run and fall-run spawning and steelhead rearing conditions should also be protected. An appropriate alternative management strategy may include reducing reservoir releases during the winter and spring months to conserve the coldwater pool for as long as possible, recognizing that a reduction in releases will result in a reduction in the area of suitable habitat downstream below Keswick Dam (e.g., the 11-mile reach to Clear Creek), the Feather River downstream of Oroville Dam, the American River downstream of Nimbus Dam, and on the Trinity River.

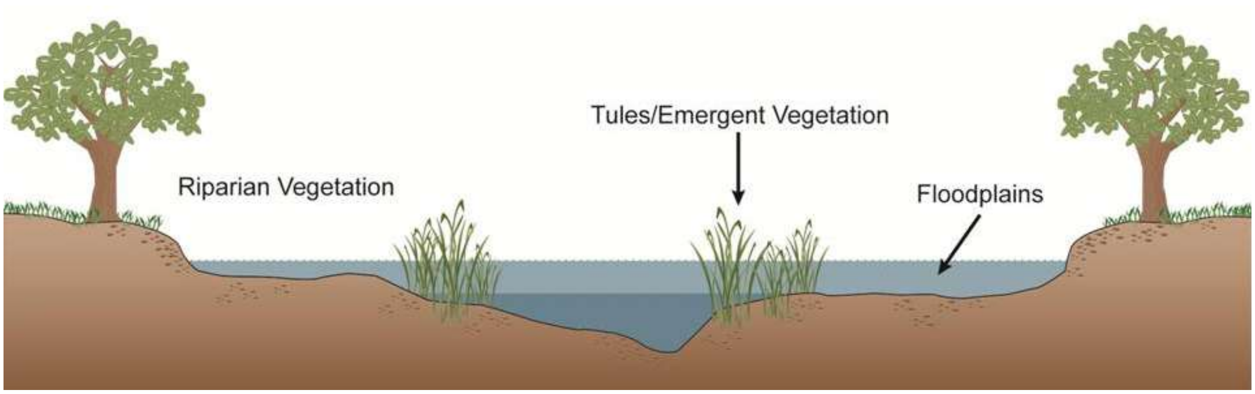

Figure 5-1. **Cross section through a natural (historic) Sacramento River channel showing the change in habitat as a function of changes in river flow.**

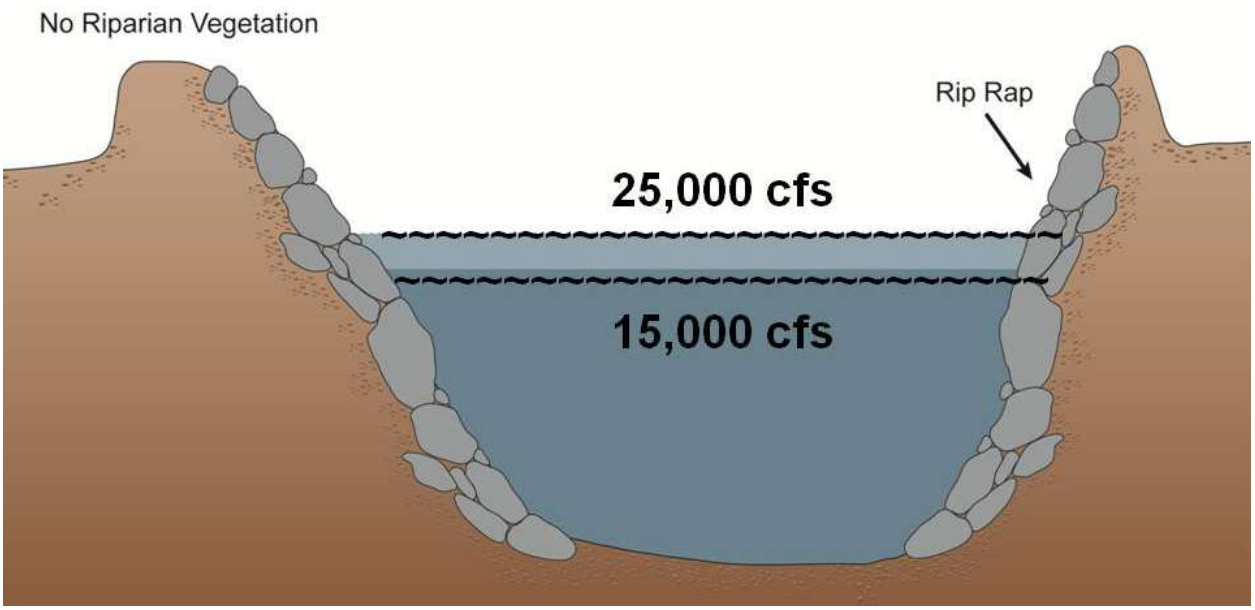

Figure 5-2. **Cross section through a channelized reach of the Sacramento River showing the change in habitat as a function of changes in river flow.**

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6 Linkage between River Flow and Salmonid Survival

Over the last twenty-five years numerous studies have been conducted in the Sacramento and San Joaquin river systems and in the Delta to examine migration pathways, migration rates, and survival, and to investigate how changes in river flows affect juvenile salmonids migratory processes (e.g., Kimmerer 2008; Blake *et al.* 2012; Newman and Rice 1988, 2002; Newman and Brandes 2009; Baker and Morhardt 2001, Newman 2008; Brandes and McLain 2001; Perry 2010; Michel 2010; SJRGA 2011). Ongoing acoustical tag investigations are currently examining juvenile salmonids and steelhead movement patterns in response to river flow and to tidal hydrodynamics within the Delta (e.g., 2012 Stipulation Study, Six-Year Steelhead Survival Study, NMFS Sacramento River acoustic studies, etc.). These studies, which are discussed in greater detail in Sections 7, 8, and 9 indicate that:

- The relationship between river flow and juvenile salmonid survival is weak (large changes in river flow are needed to achieve even a small change in salmonid survival).
- Factors other than flow, including exposure to elevated water temperatures and predation, impact survival and reduce potential benefits of changes in river flows.
- Hydrologic conditions in the Sacramento River provide good conditions for juvenile salmon migration, including continuing seasonal flow pulses that serve as migration cues.
- Salmon survival in the San Joaquin River has declined over time independent of river flow, apparently due to increased predation mortality.
- Tidal hydrodynamics are important for migration and survival of juvenile salmonids in the Delta. Greater upstream flow releases will not overcome this tidal influence.
- Increasing seasonal flow alone will not restore many of the functions that the rivers and Delta provided historically (e.g., increased access to suitable rearing habitat in channelized reaches, etc.).
- Newly developed analytical tools are improving our ability to track juvenile salmonids and to better understand their movements and needs.
- The Particle Tracking Model (PTM) is not an appropriate tool for evaluating juvenile salmonid behavior.

6.1 General Significance of River Flows for Salmonids

River flows support a variety of important functions for salmonids (Section 5). River flow and associated olfactory parameters serve as the environmental cues for adult salmonid attraction and upstream migration to natal spawning habitat. Instream flows are needed to provide sufficient water depths for adult upstream passage and adult holding in the river's upper reaches prior to spawning (Williams 2006). River flows also help to regulate water temperatures in the river's upper reaches, which currently provide suitable habitat for adult salmonid holding, spawning and egg incubation, and juvenile rearing (Boles 1988).

As a result of exposure to seasonally high air temperatures and solar radiation, particularly during the spring, summer, and fall months, water temperatures increase as a function of distance traveled downstream of a dam until thermal equilibrium is reached with atmospheric conditions. That is, once water temperature reaches thermal equilibrium in given atmospheric conditions, increasing flow does not result in a decrease in water temperatures. For example, water temperatures in the Delta during the spring period of juvenile salmonid migration are in thermal equilibrium with then-existing atmospheric conditions. As a result, and particularly in light of the distance between reservoirs and the Delta, increased releases of water from upstream reservoirs will not result in a decrease in water temperature in the Delta (Deas and Lowney 2000).

Future climate change could lead to even more elevated Central Valley water temperatures, resulting in exposing various salmonid lifestages to higher water temperatures, which would contribute to increased mortality and reduced health and abundance of salmonid species. As discussed in Sections 5, reservoir storage levels and current coldwater pool management have been important elements in maintaining suitable habitat conditions for salmonids in many Central Valley rivers, particularly under dry and critically dry hydrologic conditions (NMFS 2010a, USBR 2008).

River flow provides water depth, velocity, and wetted channel that are attributes of salmonid habitat in the upper reaches of Central Valley rivers downstream of impassable dams. Flows can provide for suitable dissolved oxygen levels, for the flushing of fine sediments that deposit on gravels used for spawning, and as a substrate for macroinvertebrate production that provides food for rearing juvenile salmonids. Flows are also needed to provide sufficient water depths for adult spawning as well as to provide interstitial flows through gravels to provide oxygen and remove metabolic waste from incubating salmonid eggs. If flows are reduced after a salmon redd has been formed and eggs deposited, the risk of dewatering the incubating eggs and egg mortality can increase. In contrast, if river flows are too high during egg incubation, gravel and eggs and alevins may be scoured out of the redd, resulting in salmon mortality (Williams 2006).

Flows also provide the transport mechanism for delivering macroinvertebrates and zooplankton downstream to areas where food is accessible to juvenile salmonids. However, if water velocities are too great, habitat quality within the river for juvenile rearing, especially fry, may be reduced (USFWS 1986). If flows and water levels fluctuate substantially, there may be an increased risk that juvenile salmonids will be stranded in unsuitable habitats as flows recede. This could result in mortality associated with exposure of salmon to elevated water temperatures, desiccation, and predation by birds and other wildlife.

6.1.1 Flow Levels: A Balancing Act for Salmon

Instream flow and habitat quantity is needed for salmon adults, spawning and egg incubation, and juvenile rearing within the Central Valley rivers' upper reaches and is dependent on numerous factors that frequently change over time, including stream gradient, substrate, geomorphic characteristics, and water temperatures. Too much flow can result in decreased habitat quality and availability, just as too little flow may reduce habitat conditions for various lifestages of salmonids (USFWS 1986).

On balance, imposing inflexible minimum Delta inflow or outflow requirements that require greater reservoir releases is likely to adversely impact salmonids. Requiring increased instream flows for downstream purposes may result in degrading river habitat conditions for salmonids (e.g., higher than suitable water velocities) as well as depleting reservoir storage and coldwater pool reserves needed to maintain suitable temperature conditions for salmonids during the spring, summer, and fall in upstream habitat areas. As discussed in Section 5, flow regimes that deplete coldwater pool storage and/or substantial seasonal fluctuation in instream flows, such as those that could occur with imposing a natural flow strategy, may substantially and adversely affect habitat conditions and the salmonid survival require careful analysis.

6.1.1.1 Current Flow Conditions and Functions in Central Valley Rivers as Related to Salmonids

Hydrologic conditions within Central Valley rivers and the Delta are dynamic and vary substantially in response to precipitation and runoff. Large variation in hydrology occurs between years (e.g., wet and dry years), between seasons (e.g., winter and spring and summer and fall), as well as on hourly and daily time steps. Hydrodynamic conditions within the Delta are further complicated by strong tidal dynamics where tidal flows may be an order of magnitude or greater than inflows from the tributary rivers (see SWC/SLDMWA written comments for Workshop 1). Local flow dynamics at channel junctions and those influenced by bathymetry, channel configuration, submerged and emergent vegetation, and the influence of export operations are even more complex.

A major biological challenge when working on Central Valley salmonids is understanding and predicting changes in habitat conditions and behavioral response of different salmonid species and lifestages as they encounter these changes in flow conditions. There is a relatively strong body of scientific information developed through Instream Flow Incremental Methodology studies on habitat suitability for salmon and steelhead in response to changes in water velocity and water depth based on river flow, substrate, cover, and water temperatures within the upstream habitats where salmonids spawn and juveniles rear (e.g., USFWS 1986, 1996, 2005; Bartholow 2004; USBR 2008; and Stillwater Sciences 2009). Salmonid response, particularly juveniles, to changes in flow conditions within the rivers' lower reaches and in the Delta tidal areas is much less understood.

In the past, juvenile Chinook salmon were marked with coded-wire tags (CWT) and released at various locations with their survival rates and migration rates estimated based on recaptures downstream (see Sections 7, 8, and 9 for additional discussion). Results of these mark-recapture studies were frequently difficult to interpret, included small sample sizes for recaptured fish, produced variable results, and provided no detailed information on the behavioral response of fish to flows or route selection or specific locations where mortality is high. Despite these limitations, results of an extensive number of CWT mark-recapture studies on both the Sacramento and San Joaquin rivers over the past 2 decades (hundreds of tests using tens of millions of juvenile salmon) provide useful information on trends in survival and how various factors such as river flow, Delta Cross-Channel gate operations, Head of Old River Barrier, etc.) affect survival (Brandes and McLain 2001, Newman and Brandes 2009, Kimmerer 2008, SJRGA 2006, Newman and Rice 2002).

Over the past 10 years, significant advances have been made in the applying acoustic tag technology to assess the juvenile salmonids' response to flow changes, route selection, migration rates, and reach-specific survival rates (Perry 2010, Michel 2010, SJRGA 2011, Blake *et al.* 2012, and others).

I-D acoustic tag results provide useful information about juvenile salmonids response to flow splits and reach-specific survival. 2-D and 3-D acoustic tag detection arrays have also been used to map the specific location of tagged salmonids within the water column that can then be matched with detailed information on local water velocities and current patterns at the specific location corresponding to each individual fish. Acoustic tag monitoring is virtually continuous and can be used to examine the behavioral response of fish to complex river and tidal flows during the day and at night. Using this more detailed information on fish movement and survival, in combination with monitoring flows, turbidity, water temperatures, changes in gate and export operations, etc., a more refined understanding of the response of juvenile salmonids to flows and the functions that flows serve for salmonids, is starting to emerge.

Although general information is available on the behavioral response and functions of these flow-related processes, the application of more sophisticated acoustic tagging and monitoring in the future will provide new insights into the role of flows affecting these functions and the response of various salmonid lifestages to these environmental conditions. Using this new body of scientific information, more detailed and robust analyses of the potential effects of variation in natural flows and managed flows will be developed. Information on changes in micro- and macro-habitat selection, migration timing and rates, survival, and other factors is currently being developed and analyzed. Results of these studies, both within the rivers and tidal Delta, will provide insight into how these flow-related functions can be managed and enhanced in the near future. Results of these emerging studies will also be used to assess how salmonids are using newly restored habitats with the Delta and rivers, identifying specific management actions (e.g., predator control) to improve juvenile salmonid survival, and other factors such as the use of pulse flows to stimulate migration that are intended to improve Central Valley salmonid survival and abundance in the near future.

6.2 Overview: Studies of the Relationship between Flow and Salmonid Survival

As discussed in greater detail in Sections 7, 8 and 9, many flow-survival studies results conducted on Central Valley rivers regarding juvenile salmonids show a general, but weak trend of increased juvenile survival during migration through the rivers and Delta when river flows are higher (Newman and Rice 2002, Newman and Brandes 2009, Newman 2008, SJRGA 2006, Brandes and McLain 2001). However, these survival studies show: (1) high variability in the actual survival of juvenile salmonids at a given flow, as reflected in the scatter of survival estimates (observations of both high and low survival at a given flow); (2) low r^2 values (reflecting that the relationship between survival and flow is weak and flow alone does not explain a substantial proportion of the observed variation in juvenile survival); and (3) based upon the low slope of the flow-survival relationship, that a substantial increase in flow is required to achieve a relatively small predicted increase in salmonid survival. Results of the studies conducted to date, however, have been based on simple relationships with river flow alone and have not separated the effects of increased flows with low turbidity reservoir releases from the functions provided by natural flow that also include increased turbidity. Such increased turbidity is expected to serve to improve juvenile survival through reducing the risk of predation mortality.

The high observed variation in the flow-survival relationship for juvenile salmonids (primarily based on mark-recapture results for fall-run and late fall-run Chinook salmon produced in Central Valley fish hatcheries) reflects, in part, the large number of factors other than river flow that affect species survival (Section 2). As just one example, salmonid exposure to predation is a major factor affecting juvenile survival. Indeed, migration studies show 50 percent or more of migrating juvenile salmonids are lost before they reach the Delta (Michel 2010, MacFarland *et al.* 2008).

Several conceptual models have been advanced to support the notion that higher instream flows will benefit juvenile salmonid survival. One suggested mechanism is that, at higher flows, the downstream rate of juvenile migration would be faster and, therefore, juvenile salmonids would have reduced exposure to potential predators. However, the available data do not support this theory. Results of CWT and acoustic tag studies discussed more thoroughly below indicate that while juvenile downstream migration transit time in portions of the Sacramento River upstream of the Delta may decrease as instream flows increase, salmonid migration rates in the Delta actually decrease as the juveniles move downstream into areas subject to tidal influence (Michel 2010). These studies show that the relationship between river flow and migration rates (time from release to recapture downstream at Chipps Island) is very weak and does not support the theory that increasing river flow will result in faster migration rates through the Delta or reduced exposure to in-Delta predation mortality (see Sections 7, 8, and 9).

A second suggested mechanism is that juvenile salmonids use changes in river flow and turbidity as environmental cues for downstream migration. Increased flow and increased turbidity (and potentially concurrent decreased air and water temperatures) typically occur in response to stormwater runoff in the Central Valley watersheds. As flows increase and turbidity becomes more elevated, the conceptual model would suggest that juvenile salmonid vulnerability to predators such as striped bass and largemouth bass would decrease which, in turn, would contribute to increased juvenile salmonid survival during migration. However, the data do not consistently support these predictions. Results of field monitoring studies do not show that pulse flows releases from upstream reservoirs provide the same biological cues and functions as naturally occurring storm events. Several studies have been conducted in Central Valley rivers that use short-duration (days) managed pulse flow releases from reservoirs in an effort to stimulate the downstream movement of juvenile salmon (e.g., pulse flow studies conducted on the Mokelumne River by EMBUD (unpub. data) and on the Stanislaus River (Demko and Cramer 1995, 1997 and Demko *et al.* 2000, 2001). These tests have produced variable and inconclusive results.

Smolt migration appears to be controlled largely by growth rate and fish size, physiologic transformation to smolts (e.g. ATPase levels), and patterns of seasonally increasing water temperatures. The studies suggest that natural pulse storm flow events and increased turbidity are likely important migration cues for juvenile salmonids. However, higher, stabilized flows via required instream flows, pulse flow releases, or similar mechanisms do not provide a similar benefit to juvenile salmonids. Thus, stabilizing river flows in a manner that reduces or eliminates pulse flow variation needed for juvenile salmonid migration cues (i.e., “flat lining” river flows) is unlikely to provide meaningful benefit to salmonid migration (del Rosario and Redler undated, Jager and Rose 2003).

To a large extent, existing reservoir operations during the winter and spring months (most of which are primarily designed to meet flood control requirements and to control runoff from local watersheds and tributaries) help to maintain the pulse flow and turbidity cues that are important for salmonids.

In sum, the functions and inter-relationships among flow and habitat quality and availability, growth, survival, reproductive success, and abundance of salmonids are complex. The available data show that there is high variability and low certainty/predictability in flow-survival relationships, although the data also show a general trend toward increased salmonid survival as flow increases during downstream migration. Fixed flows or managed pulse flow releases are unlikely to provide significant benefit to the species. As discussed in Section 5, such releases may actually deplete coldwater pool volumes in a way that harms salmonids. At base, the focus should be on improving habitat functions for salmonids, not simply releasing more water to arbitrarily increase flows.

6.2.1 Improved Monitoring Technology and Analytical Tools

The ability to respond flexibly to current in-river and reservoir conditions, through coldwater pool management and application of near-real time monitoring results, has improved conditions for salmonids over the last 3 decades. Improvements in monitoring technology and analytical tools have also helped to address uncertainty in evaluating the response of juvenile salmonids to factors such as route selection, behavior, survival, and flow changes (including river flow, Delta tidal hydrodynamics, and export operations [Perry 2010; Michel 2010; SJRGA 2010, 2011]).

The Instream Flow Incremental Method and other analytical tools have been developed and applied to Central Valley rivers for use in evaluating instream flow schedules that meet the habitat requirements of the various lifestages of salmonids (e.g., USFWS 1996, 2011, and others). Acoustic tag technology (Figure 6-1) has been used to develop detailed information on juvenile salmon and steelhead migration through the Delta. The technology is continuing to be refined and improved to provide better signal transmission, longer battery life, smaller tag size and the ability to successfully tag smaller salmonids. There have also been marked improvements in technologies designed for tracking and mapping juvenile salmonid movement in three dimensions.

Data obtained from application of these new and improved technologies can be analyzed in conjunction with information about local flow patterns to improve habitat and passage conditions for juvenile salmonids. The technologies can also be used to analyze the benefits of fish guidance projects, such as non-physical barriers (e.g., the “bubble curtains” tested in the San Joaquin River at the Head of Old River and on the Sacramento River at Georgiana Slough) (Bowen *et al.* 2009, Bowen and Bark 2010).

Data generated using these improved monitoring technologies are now being integrated into analytic tools designed to improve our understanding of salmon biology, the response of juvenile salmonids to flows and other environmental conditions, and the role of predation in juvenile salmonid mortality. The predictive capacity of models and other tools has also improved, particularly with their integration into life cycle modeling efforts. The rapid development of these new tools has only recently begun, and these efforts are continuing to expand and provide new information that will be directly applicable to informing management decisions in the future. For example, NMFS and others are currently conducting a large-scale acoustic tag study of juvenile hatchery and wild salmonids migrating through the upper Sacramento River and its tributaries downstream through the Delta; however, results of this large-scale study are not expected to be available for several years (Hayes 2012, Klimley *et al.* 2012).These circumstances point to the idea that the science should be allowed to develop, and maximum flexibility in management and operations should be retained to implement what the scientific data show and will show.

6.2.1.1 PTM is an inadequate tool for predicting movement of juvenile salmon

PTM has been used to predict how juvenile salmonid may respond to different water export management strategies and to justify regulation of Delta flow rates, such as OMR flow levels, during the spring period of juvenile salmonid migration through the Delta (See 2009 NMFS Biological Opinion RPA Action IV.2.3 (overturned by federal court).) However, PTM simply simulates the movement of neutrally buoyant particles in response to local flow patterns. It has been shown that neutrally buoyant particles do not provide reliable predictions of the movement of juvenile salmon and steelhead, both of which swim actively and respond behaviorally to their environment (NMFS 2012).

USBR and DWR (2009) and NMFS (2012) report results of a test to validate PTM results as they apply to predicting the movement of juvenile Chinook salmon. The study examined the relationship, or lack thereof, between PTM predictions and observations of CWT salmon released in April-May as part of the Vernalis Adaptive Management Plan (VAMP) and earlier San Joaquin River survival studies (1995-2006) and recaptured in Chipps Island trawling. Results of the test (Figures 6-2 and 6-3) confirmed that PTM results are not a reliable predictor of salmon movement and are inappropriate for developing and evaluating the effects of management actions on movement and survival of juvenile Chinook salmon. Actual monitoring of juvenile salmon migration, survival, and response to local hydrodynamics using acoustically tagged fish (Figure 6-1) has recently provided new scientific information on actual juvenile migration rather than relying on PTM simulation runs.

Newly developed analytic tools, including the DPM (Section 4), serve as more informative analytical frameworks for analyzing acoustic tag monitoring and other data related to movement and survival of juvenile salmonids. These new tools have proven to be more valuable instruments than PTM for evaluating juvenile salmonid movement patterns and survival in response to potential management actions, such as increased Delta inflows and outflows, modified exports and changes in OMR flow levels.

Additional information on river flows and hydrologic conditions in the Central Valley rivers is presented in the SWC/SLDMWA written comments submitted in conjunction with and during the State Board’s workshop on Ecosystem Changes.

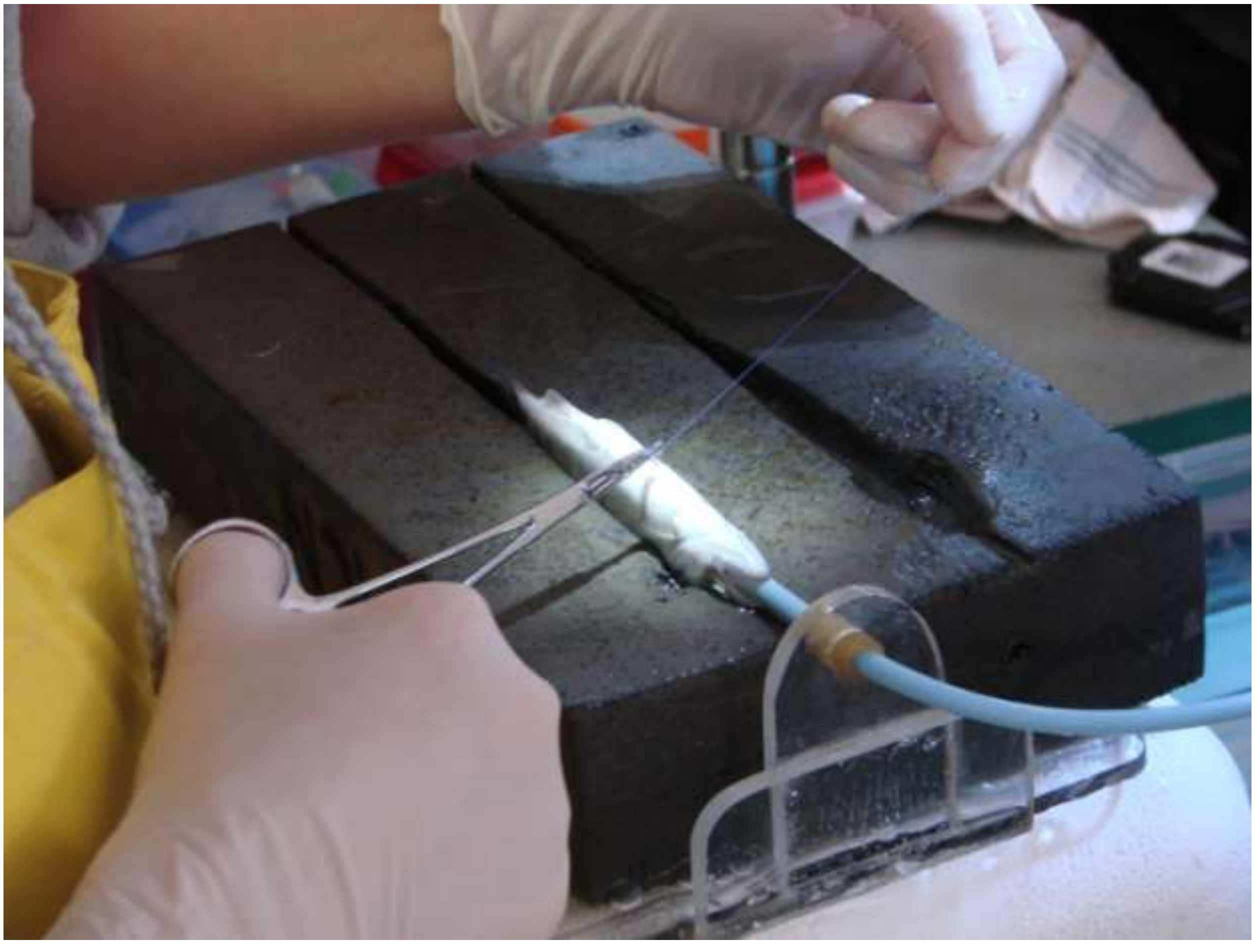

Figure 6-1. Surgically implanting an acoustic tag into a juvenile Chinook salmon.

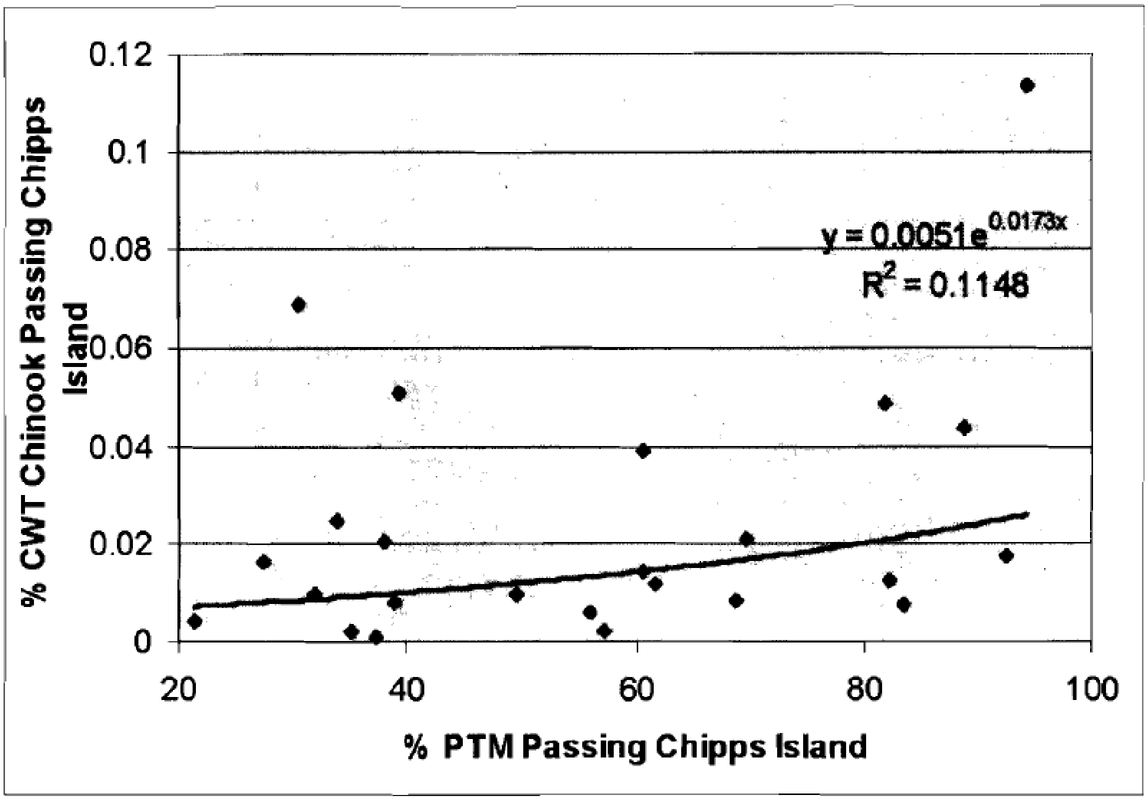

Figure 6-2. Results of a validation test of the percentage of particles in a PTM model scenario passing Chipps Island and corresponding percentage of CWT juvenile Chinook salmon to Chipps Island (Source: USBR and DWR 2009, NMFS 2012).

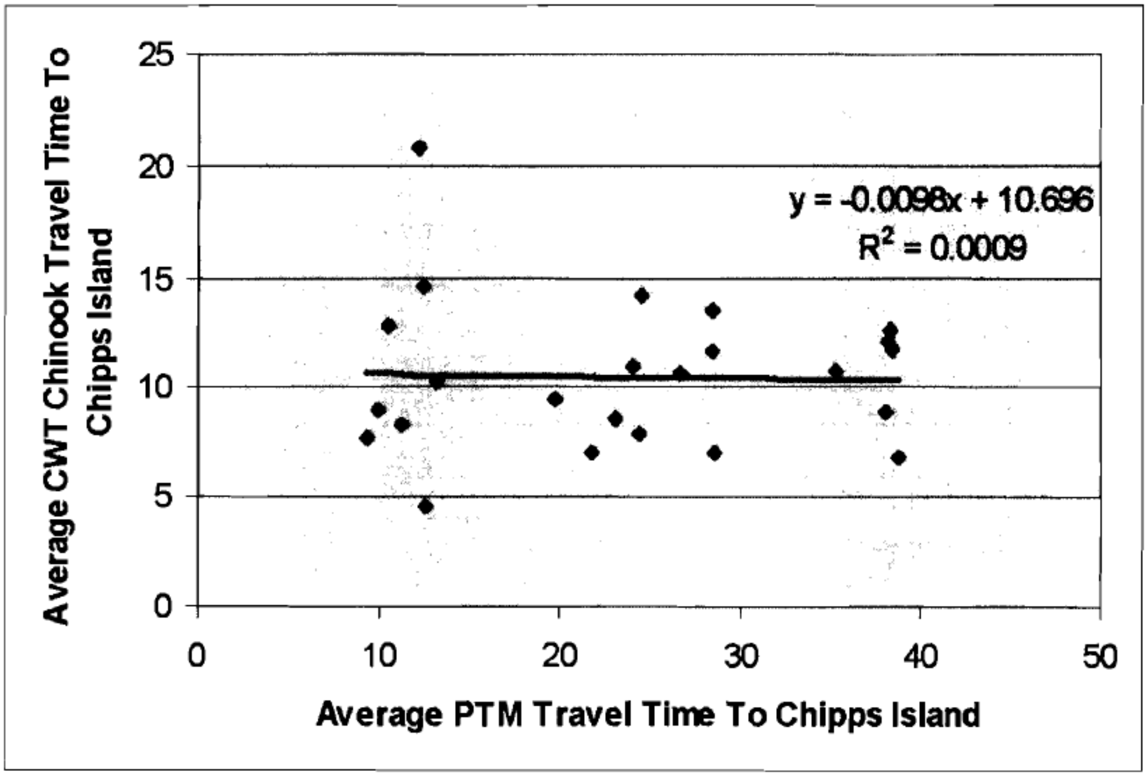

Figure 6-3. Results of a validation test of the travel time of particles in a PTM model scenario passing Chipps Island and corresponding average travel time of CWT juvenile Chinook salmon to Chipps Island (Source: USBR and DWR 2009, NMFS 2012).

6.2.1.2 Addressing Uncertainty

Scientific monitoring and experimentation in the Central Valley has evolved significantly over the past several decades. Rapid advances in the precision and level of detail available on movement patterns, survival, and the response of juvenile salmonids have been made over the past 10 years with the application of acoustic tagging technology. These advances serve to improve and refine our understanding of the functions of river and tidal hydrodynamics, and other factors, for salmonids and help reduce the level of uncertainty in the evolving scientific foundation for identifying and testing alternative management strategies. The level of uncertainty now and in the future is expected to be further reduced based on the following:

- The continued development of an integrated multidisciplinary collaborative monitoring program;
- Continued development and refinements to monitoring tools such as 3-D acoustic tag tracking;
- Continued research to evaluate functions and processes that are proving to be beneficial in habitats such as Liberty Island, Yolo Bypass, Suisun Marsh and elsewhere;
- Collaboration with research investigations on similar salmonid issues in the Northwest;
- Developing habitat restoration projects that are based on habitat suitability of various species and lifestage, reflect natural functions and processes such as sediment resuspension (turbidity);
- Development of new analytical tools, models, and statistical analyses that can be used as a framework for organizing and integrating research results;

Despite these efforts, variation and uncertainty will continue to be part of future management. Hydrologic variation within and among years, the occurrence of extended drought, introduction and colonization by additional non-native species that may impact food supplies and trophic dynamics, and predator-prey balance remain future uncertainties. The timing, magnitude, and effects of future climate change affecting Central Valley hydrology, temperatures, and ocean-rearing conditions for salmonids are major areas of future uncertainty. Management and monitoring strategies in the future will need to be flexible and adaptable to respond to these and other changes, and areas of uncertainty.

6.3 Recommendations

Analytical tools and applying emerging technologies, such as improving acoustic tag monitoring, provide the current scientific foundation for rapid advances in the body of scientific information on how salmonids respond to environmental factors. These near-future advances will provide new insights into flow functions in context with various other environmental factors that affect spawning and reproductive success, juvenile rearing, migration patterns and survival within the rivers and Delta. There continues to be uncertainty in these functional relationships that will be reduced through applying new tools in the near future.

7 Sacramento River System

7.1 Background on Salmonid Use of the Sacramento River System

The Sacramento River and its tributaries, including the American, Feather and Yuba rivers, and Battle, Clear, Butte, Deer, Mill and numerous other creeks tributary to the river, support populations of Chinook salmon and steelhead. Fall-run, late fall-run, spring-run, and winter-run Chinook salmon as well as Central Valley steelhead are produced in the Sacramento River watershed. The watershed also provides habitat for resident rainbow trout and various other fish and aquatic species. Salmon and steelhead are also produced in hatcheries located on the American and Feather rivers and Battle Creek. Habitat conditions for salmonids in the main rivers are affected by instream flow releases from upstream dams that also directly influence water temperatures in the main river channels immediately downstream from the dams. The geographic distribution of primary spawning and juvenile rearing habitat in the Sacramento River basin for salmonids is shown in Figures 1-3, 1-4, and 1-5.

Habitat conditions for salmonid spawning, rearing, and migration in the Sacramento River basin's major rivers have been severely modified as discussed in Section 2. In addition, introducing non-native fish and other aquatic species such as striped bass, largemouth bass, American shad, threadfin shad, silversides, and other predators has altered fish community dynamics within the Sacramento River watershed. Annual variation in hydrologic conditions within the watershed has also resulted in wide variation in habitat conditions, particularly in wet year flood conditions and dry year drought conditions.

In response to these and other factors, salmonid populations in the Sacramento River watershed have experienced both high and low abundance periods (GranTab 2011). Winter-run and spring-run Chinook salmon population abundance (adult escapement), as well as Central Valley steelhead abundance, have shown a general declining trend over the past 3 decades. Fall-run Chinook salmon are the most abundant salmonid inhabiting the basin and have also had the greatest support by hatchery production. Although fall-run salmon abundance has fluctuated substantially in recent years, the species continues to support both commercial and recreational harvest (Boydstun 2001). A number of stressors affect these species directly and indirectly (Section 2) as do a number of specific management requirements and programs intended to enhance and protect salmonid species and their habitats (Section 3).

7.1.1 <u>Winter and Spring Pulse Flows</u>

As discussed above, juvenile Chinook salmon and steelhead have evolved to respond to pulse flows and increased turbidity associated with storm activity during the winter and spring juvenile migration period. There has been concern that upstream reservoir storage operations could virtually eliminate short-duration flow cues for salmonids on the lower Sacramento River in the winter and spring (NMFS 2010a). To test this hypothesis, we analyzed pulse flow conditions using river daily flow measurements at the Red Bluff Diversion Dam (RBDD) over the period May 2005 through April 2006 to reflect conditions in the upper reaches of the Sacramento River. We used DAYFLOW data of daily flows at Freeport to represent flow conditions in the lower reaches of the Sacramento River. (DAYFLOW data were compiled for the period from December through May for the period from 2001 through 2011 using daily flows, a 3-day running average and a 7-day running average.)

Analysis of results of daily flows for one example year at the RBDD are shown in Figure C-1 in Attachment C. Analysis of results of daily flows at Freeport are shown in Figures C-2 through C-12.

These data show that there is substantial daily flow variation (peak pulse flows greater than two times the baseflow) in the upper and lower river reaches of the Sacramento River in response to storms and precipitation, reservoir releases, and runoff events within the watershed. Variation in natural flows and turbidity within the mainstem and tributaries during the winter and spring juvenile salmonid migration period will continue to provide environmental cues and opportunities for juvenile emigration from the Sacramento River system.

7.1.1.1 Juvenile Chinook Salmon Survival in the Sacramento River

Numerous significant experimental studies have been conducted to assess juvenile Chinook salmon survival as they migrate downstream through the Sacramento River and Delta (Brandes and McLain 2001, USFWS unpub. data). The survival studies began in 1993. CWT juvenile salmon were released at various locations in the upper reaches of the Sacramento River, and survival was estimated based on tagged salmon recaptures in trawling at Chipps Island. These CWT studies were repeated using salmon of various origins and sizes, and changing seasonal timing of release, location of release, and environmental conditions, most notably variation in Sacramento River flows. Data from upper Sacramento River releases are available from over 100 studies conducted by USFWS. More recently, acoustic tag studies have been conducted to estimate the survival of juvenile Chinook salmon (primarily late fall-run Chinook salmon produced in the Coleman National Fish Hatchery located on Battle Creek near Redding). The acoustically tagged salmon are released into the upper river, and their survival is estimated based on acoustic monitoring at various locations along the river, Delta, and San Francisco Bay estuary (Michel 2010, Perry 2010).

Examples of reach-specific survival estimates for late fall-run Chinook salmon migrating downstream in the Sacramento River developed by MacFarland *et al.* (2008) are shown in Figure 7-1. Results of this study showed that juvenile salmon experienced relatively high mortality in the upper reaches of the Sacramento River, upstream of the Delta, with approximately 70 to 80 percent of the juvenile salmon lost in the riverine reaches of the system before entering the estuary. The study also showed that the overall mortality of juvenile salmon migrating downstream through the Sacramento River and Delta averaged approximately 90 percent (10 percent survival) by the time the fish entered coastal marine waters through the Golden Gate.

The MacFarland study results were consistent with the results of a 3-year acoustic tagging study conducted by Michel (2010) using late fall-run Chinook salmon as they migrated from the upper Sacramento River downstream through the Delta and Bay (Figure 7-2). Both studies showed approximately 95 percent mortality between the upper river release sites and coastal marine waters Overall, the survival rate from the upper Sacramento River to the Golden Gate was 3.9 percent (+/- 0.6 percent for studies conducted in 2007, 2008, and 2009; Michel 2010).

Although the reach-specific mortality rate in the upper river (above Colusa Bridge to Jelly's Ferry - river kilometers 325 to 518) in the Michel (2010) study was relatively low per 10km reach, the cumulative mortality over the long migration through the upper reach showed substantial juvenile salmon losses before they reach the Delta and Bay. The lowest survival rates, observed by Michel (2010), typically occurred in the San Francisco estuary (Golden Gate to Chipps Island - river kilometers 2 to 70), where survival ranged from 67 to 90 percent per 10km reach, as compared with survival in the Delta (93.7 percent/10km; Chipps Island to Freeport - river kilometers 70 to 169), similar to that observed in the upper reaches of the Sacramento River (Figure 7-2). The highest survival rates per 10km segment were observed in the lower Sacramento River reach (98.1 to 100 percent/10km; Freeport to above Colusa Bridge - river kilometers 169 to 325). Results of the acoustic tag study conducted by Michel (2010) also showed that juvenile salmon migration rates are not constant; instead, they vary between the riverine reaches, Delta, and estuary. Migration rates were greatest in the riverine reach and decreased as the tagged salmon moved downstream into more tidally dominated habitats in the Delta, Suisun, San Pablo, and central San Francisco Bay (Figure 7-3).

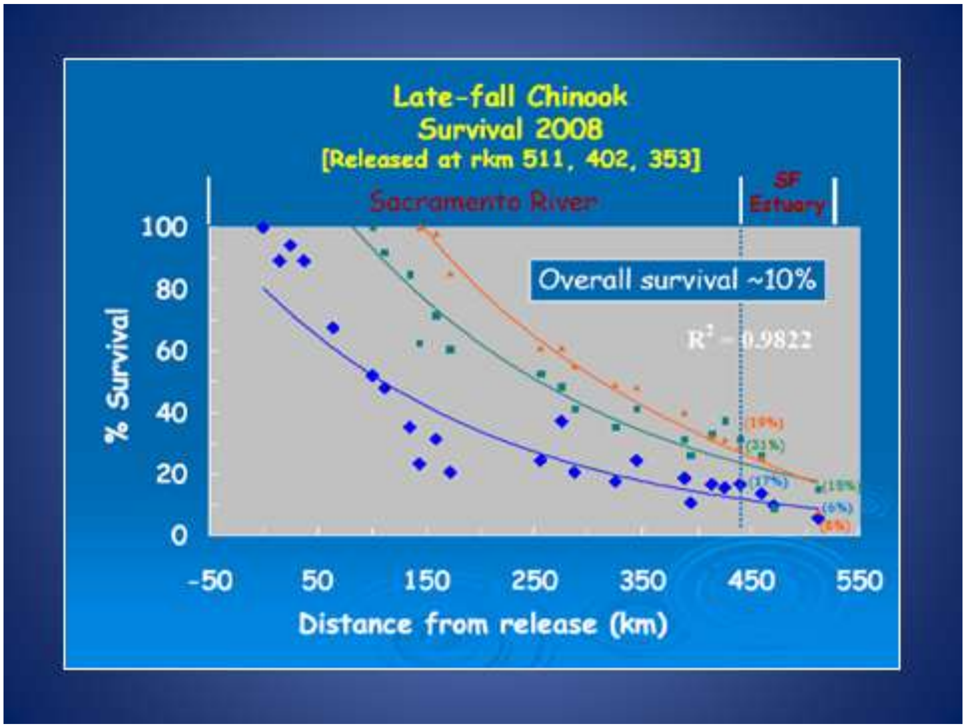

Figure 7-1. **Results of acoustic tag studies on late fall-run Chinook salmon survival during migration through the Sacramento River, Delta, and estuary (Source: MacFarland *et al.* 2008)**

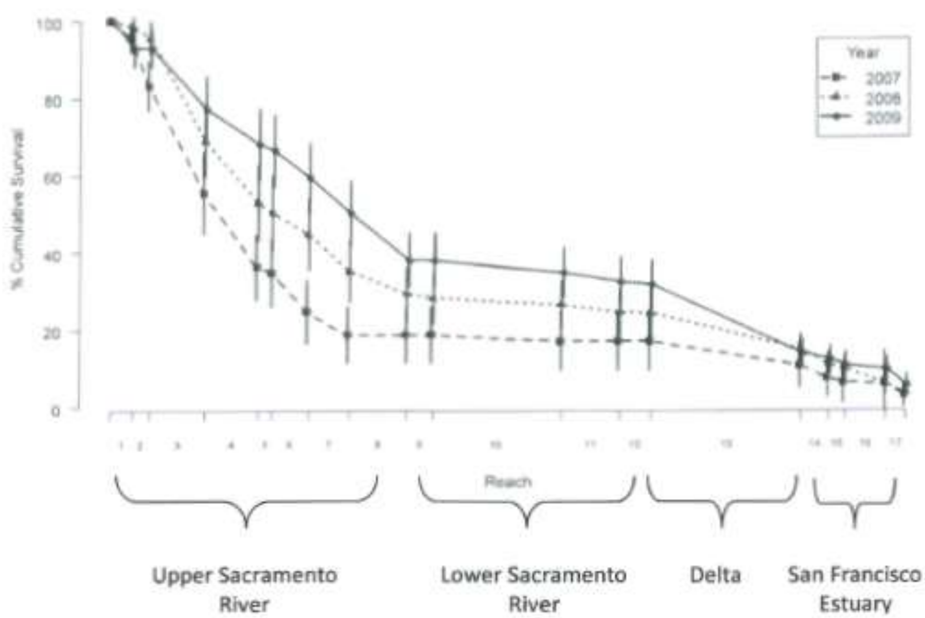

Figure 7-2. **Reach-specific survival estimates for late fall-run Chinook salmon juveniles migrating downstream in the Sacramento river, Delta, and estuary over 3 years (Source: Michel 2010).**

An important question in evaluating results of all mark-recapture studies (both CWT and acoustic tag) is whether results derived from studies using hatchery-reared salmon are representative of the behavior and survival of wild salmon. Results of a very preliminary set of acoustic tag tests by Michel (2010) suggest that, although the point estimates of reach-specific survival for hatchery and wild salmon are similar (Figure 7-4), the hatchery salmon appear to have greater variability in survival when compared to wild salmon.

A similar issue arises regarding the use of late fall-run Chinook salmon for acoustic tagging because they are larger yearling fish and more easily tagged using current acoustic technology than are smaller fish (Perry 2010, Perry *et al.* 2010). Data obtained from these larger yearling salmon may not be representative of survival and migration behavior of smaller young-of-the-year salmon fry and smolts (Perry 2010, Zeug *et al.* 2012, S. Hayes pers.com). In addition, studies conducted using Chinook salmon may not be representative of survival of yearling steelhead migrating through the Sacramento River watershed and Delta. Moreover, although results of these acoustic tagging studies provide valuable information on movement and survival of juvenile salmon, they have been conducted over only a few years under a limited range of environmental conditions. Thus, the data obtained are likely insufficient standing alone to evaluate flow-survival relationships for juvenile salmon. Similar studies using juvenile steelhead, wild and hatchery stock comparisons, and salmon smaller than the relatively large yearling late fall-run Chinook are beginning in 2012 by NMFS. The issue of using surrogate species, such as hatchery produced Chinook salmon as a surrogate for wild salmon, has been raised as a concern (Murphy *et al.* 2011, Smith *et al.* 2002, Wiens *et al.* undated). Results of comparative survival studies using various species of hatchery and wild stocks will provide useful insight into the application of surrogates in determining migration and survival rates for Central Valley salmonids.

7.1.1.2 Flow-Survival and Effects of SWP/CVP Exports on Salmon Survival

Juvenile Chinook salmon and Central Valley steelhead migrate from upstream rearing habitat through the Delta and into coastal marine waters. Juvenile migration within the Delta typically occurs during the winter and spring months. During their migration through the Delta, juvenile salmon and steelhead are vulnerable to direct losses (entrainment and salvage) at the export facilities as well as mortality from a variety of other sources. These other sources of mortality (stressors) include predation by fish (e.g., striped bass, largemouth bass, Sacramento pikeminnow, etc.) and birds; exposure to toxins; entrainment at unscreened agricultural, municipal, and industrial water diversions; exposure to seasonally elevated water temperatures; and other factors (NMFS 2010a).

It has been hypothesized that changes in Delta channel hydrodynamics may indirectly affect juvenile salmon and steelhead survival by modifying tidal and net downstream current patterns in a manner that alters their migration pathways, thereby increasing their vulnerability to interior Delta mortality sources (Kimmerer 2008). For example, it has been hypothesized that changes in the direction and magnitude of tidal and current flows within the central Delta (e.g., Old and Middle rivers) during the salmonid emigration period leads to movement of juveniles into the central Delta which, in turn, contributes to delays in downstream migration and increased salmonid mortality (NMFS 2009).

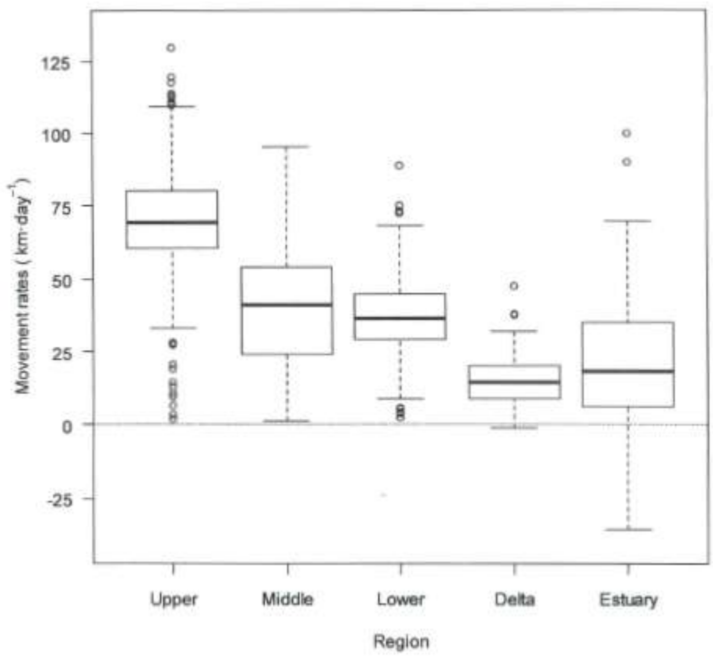

Figure 7-3. Reach specific migration rates for acoustically tagged late fall-run Chinook salmon in the Sacramento River, Delta, and estuary (Source: Michel 2010).

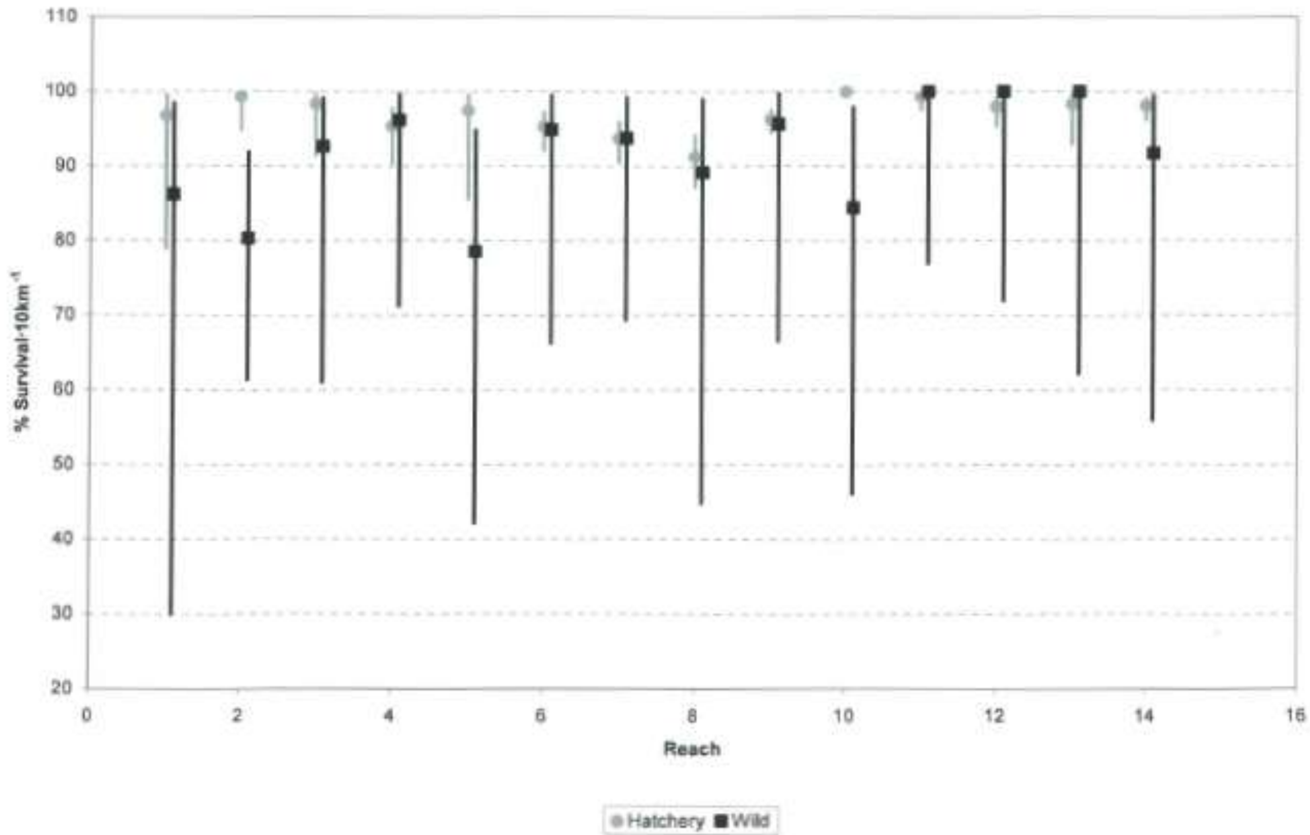

Figure 7-4. Results of a preliminary comparison of survival rates for wild and hatchery origin juvenile Chinook salmon in the Sacramento River, Delta, and estuary (Source: Michel 2010).

According to this hypothesis, the survival of juvenile salmon and steelhead migrating through the Delta would be lower when export rates are high, and salmonid survival would be higher when exports are low. However, the purported incremental contribution, if any, of higher SWP and CVP export levels to total mortality of juvenile salmon and steelhead during migration through the Delta has not been quantified.

7.1.1.3 Survival Study Analysis

To help address these management questions, additional analyses have been conducted using results of CWT studies designed and implemented by USFWS to investigate survival relationships for juvenile salmon migrating downstream through the Sacramento River and Delta. The USFWS has conducted over 100 survival studies on the Sacramento River using juvenile winter-run, spring-run, and fall-run Chinook salmon over the past 3 decades. The juvenile salmon used in these studies have primarily originated in the Coleman National Fish Hatchery and the Livingston-Stone Fish Hatchery, both located on Battle Creek, a tributary to the Sacramento River upstream of the RBDD.

Limited CWT tests have also been performed using wild juvenile salmon collected from the Sacramento River and tributaries. For this analysis, survival study results where the marked salmon were released into the upper reaches of the river system were used to represent juvenile Chinook salmon emigrating from upstream rearing areas (e.g., Sacramento River, Clear Creek, Butte Creek, etc.). These upstream releases typically occurred during the winter and spring months coinciding with the seasonal period and conditions when wild salmon and steelhead migrate downstream through the lower river and Delta. The studies included juvenile salmon typically ranging in length from approximately 50 to 110 mm. The survival study data utilized were limited to those tests in which more than 10,000 fish were released. Limiting the analysis to these larger releases was intended to increase the statistical reliability of the study results and the probability that CWT salmon would subsequently be detected in recapture sampling at the export facilities and at Chipps Island. Survival estimates were calculated for multiple tag codes when more than one tag code was used in a release. The CWT mark-recapture CWT releases used in our analysis included results from 118 studies with a combined total of over 14,200,000 juvenile salmon released.

For each of the CWT survival studies, marked fish were collected at the SWP and CVP fish salvage facilities as part of routine monitoring. The numbers of marked fish were expanded to account for the time spent sampling at each facility in accordance with standard procedures for fish salvage monitoring (expanded salvage estimates were compiled by USFWS for each CWT group). Marked salmon were also recaptured by USFWS in trawling conducted at Chipps Island, located within Suisun Bay in the western Delta, and used to calculate survival estimates based on expansion for sampling effort (all survival estimates were calculated by USFWS). Survival estimates from CWT studies based on USFWS fishery sampling for juvenile salmon at Chipps Island has been found to be highly correlated (r^2= 0.76) with the independent measure of salmon survival based on expanded catch of adults in the ocean (SJRGA 2006). As part of routine fishery monitoring during the survival studies, information on the date of release for each tag code as well as the initial and final dates of recapture is recorded.

The dates of release and the last dates of recapture in each study were used in our analyses to estimate the rate of migration of juvenile salmon downstream through the Delta and to assess the flow and export conditions that occurred within the Delta during the migration period. For purposes of this analysis, two periods were used to assess flow and export conditions for each CWT release group: average conditions 30 days and 60 days prior to the date of last recapture. The range in dates reflects the variability in the duration of fish passage through the Sacramento River and Delta observed in these studies and the conditions within the Delta during downstream passage. Information on hydrologic conditions during each CWT survival study, including Sacramento River flow, Delta inflow, SWP and CVP combined exports, and Delta outflow was obtained from the DWR DAYFLOW database. We used the results of the survival studies to analyze the potential relationship between SWP and CVP export rates and both direct losses (percentage of each tagged group of salmon recaptured at the fish salvage facilities) and indirect (total) juvenile salmon mortality during migration through the river and Delta.

7.1.1.3.1 Direct mortality of juvenile salmon and steelhead and diversion rates at the SWP and CVP export facilities

For these analyses a direct loss index, as a result of SWP and CVP export operations, for each CWT survival test was calculated based on the percentage of the number of fish released and the expanded estimate of salvage of that tag group in the combined SWP and CVP fish salvage. For the study data analyzed, the percentage of CWT salmon released into the upper Sacramento River collected at the fish salvage facilities averaged 0.03 percent (n=118; 95 percent CI = 0.0145), with a range from 0 to 0.53 percent. The estimated percentage of each CWT group recaptured at the SWP and CVP fish salvage facilities was then plotted against the average combined export rate over the 30- and 60-day periods prior to the date of the last fish recaptured.

It was hypothesized that if SWP and CVP export rates were an important factor affecting the percentage of salmon from the Sacramento River collected in export facility salvage (direct losses), the percentage of tagged fish recaptured at the salvage facilities would increase when export rates were higher. Figure 7-5 shows the results of the analysis based on average export rates for the 30 days prior to the last recapture. Results for average exports for the 60 days prior to the last recapture are shown in Figure 7-6. Results of a linear regression model with 95 percent confidence intervals are also depicted in Figures 7-5 and 7-6.

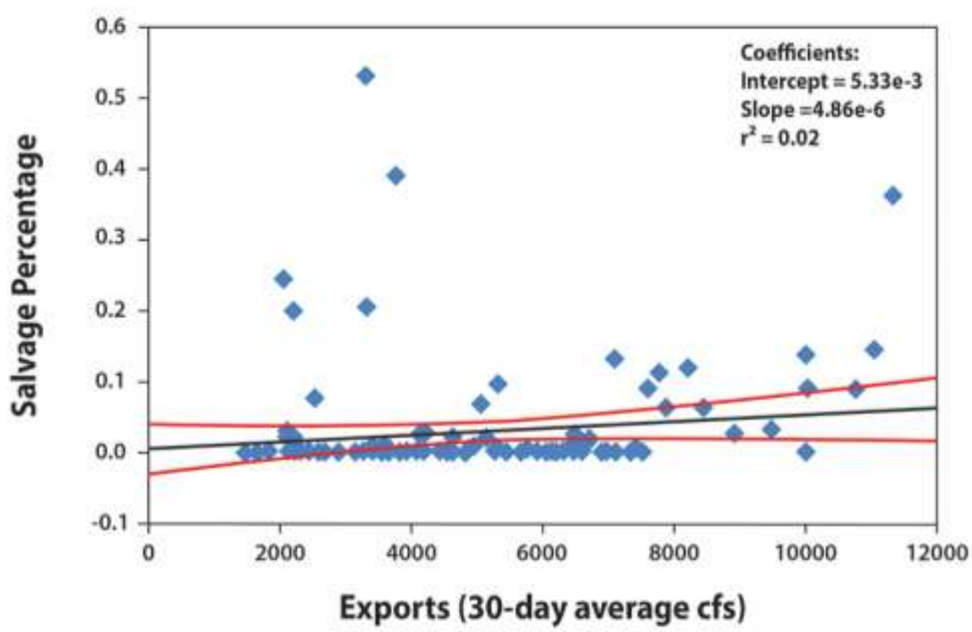

Figure 7-5. Relationship between SWP and CVP exports (30-day average) and percentage salvage (1980-2001).

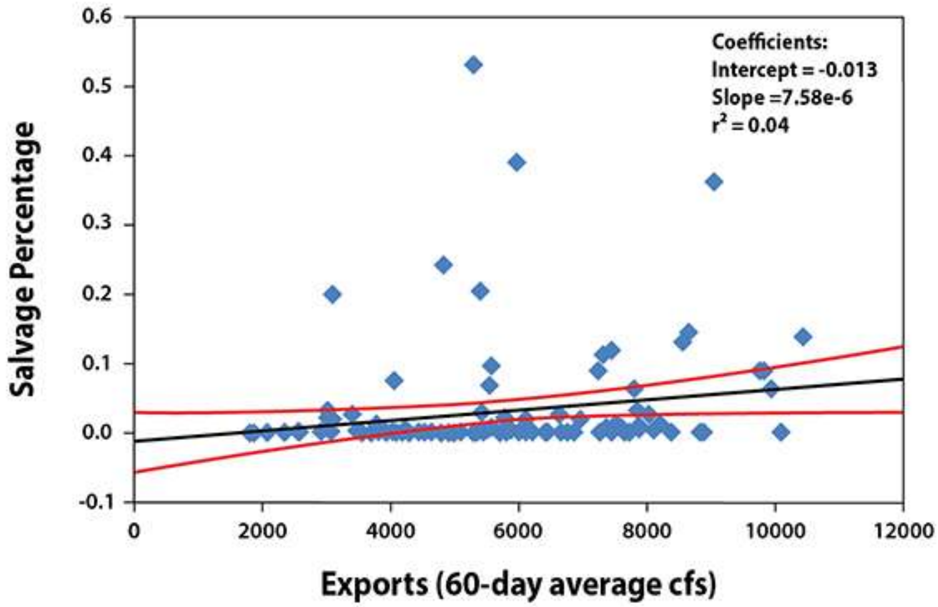

Figure 7-6. Relationship between SWP and CVP exports (60-day average) and percentage salvage (1980-2001).

Overall, results of this analysis showed that the relationship between export rate and salmon salvage was characterized by very flat slopes (slopes < 0.0001) and low correlation coefficients (r^2 = 0.02 for the 30-day exports and 0.04 for the 60-day exports). The relationship between combined SWP and CVP export rates and the percentage of each tag group recaptured (direct loss) was not statistically significant for the 30-day (p=0.12) average export rate. The relationship between the percentage of salvage and average export rate over a 60-day period was significant (p=0.04); however, the relationship was extremely weak (r^2 = 0.04). *There was no evidence based on results of these analyses of CWT data that direct losses of salmon migrating downstream in the lower Sacramento River and through the Delta experience greater direct losses as a result of increases in SWP or CVP export rates*.

Due to the level of uncertainty and variability associated with other factors affecting direct losses as well as with the underlying functional relationships, NMFS uses results of CWT salmon releases on the Sacramento River as surrogates for spring-run Chinook salmon to assess the level of incidental take at the export facilities as a percentage of juvenile salmon migration through the Delta. NMFS also uses the annual juvenile production estimate (JPE) for juvenile winter-run salmon, which estimate is used as the basis for regulating take levels (to less than 1-2 percent) at the export facilities.

7.1.1.3.2 Indirect (total) mortality of juvenile salmon and steelhead and diversion rates at the SWP and CVP export facilities

Results of salmon survival studies conducted within the Sacramento River and Delta over the past 3 decades have shown that (1) total survival (the overall survival estimate for a specific group of tagged salmon from the point of release to Chipps Island in these analyses) has been highly variable within and among years, and (2) total survival rates have been low in some years. Over the 118 survival studies included in our analysis—all based on CWT salmon released into the upper Sacramento

River—the average survival rate to Chipps Island was 0.29 (29%; n=118; 95 percent CI = 0.04) with a range from 0.016 to 1.0. (Studies in which no CWT salmon were collected were not included in the analysis; maximum calculated survival rates were truncated at 1.0).

A key question for Delta management is whether SWP and CVP export rates are a factor affecting (indirect effect) the survival of juvenile salmon during migration. If SWP and CVP exports are a major factor affecting survival within the Delta, total salmon survival should be reduced in those years when export rates are high and increased in those years when export rates are low (Figure 7-7). If SWP and CVP export rates are not a major factor affecting Delta survival, there should be no relationship between total Delta survival and combined exports during the seasonal period when juvenile salmon are migrating through the lower river and Delta (Figure 7-7).

To test this hypothesis, the estimates of total Delta survival from the CWT survival studies were plotted against average SWP and CVP export rates 30 days and 60 days prior to the date of last recapture for each CWT group of juvenile salmon between 1980 and 2001. Results of the analysis are shown in Figure 7-8 using a 30-day average for exports. In Figure 7-9, the results use a 60-day average for exports (results of the linear regression and 95 percent CI are shown for each analysis). The slopes of the regressions were low (<0.0001) and were characterized by a high variance (r^2= 0.01 for the 30-day average and 0.02 for the 60-day average).

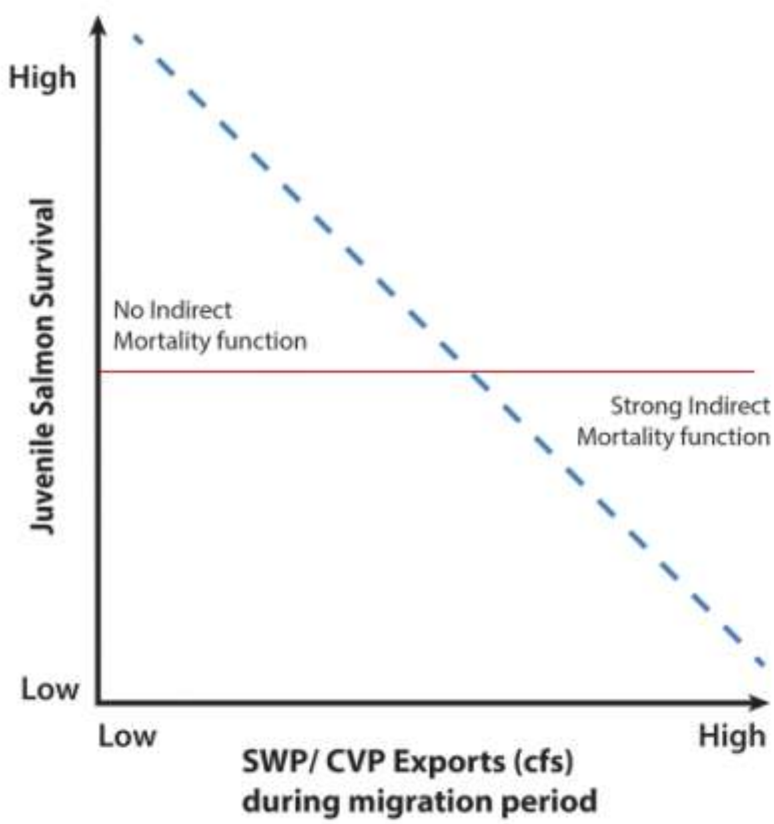

Figure 7-7. Hypothesis regarding the effect of SWP/CVP exports on indirect mortality of juvenile salmon.

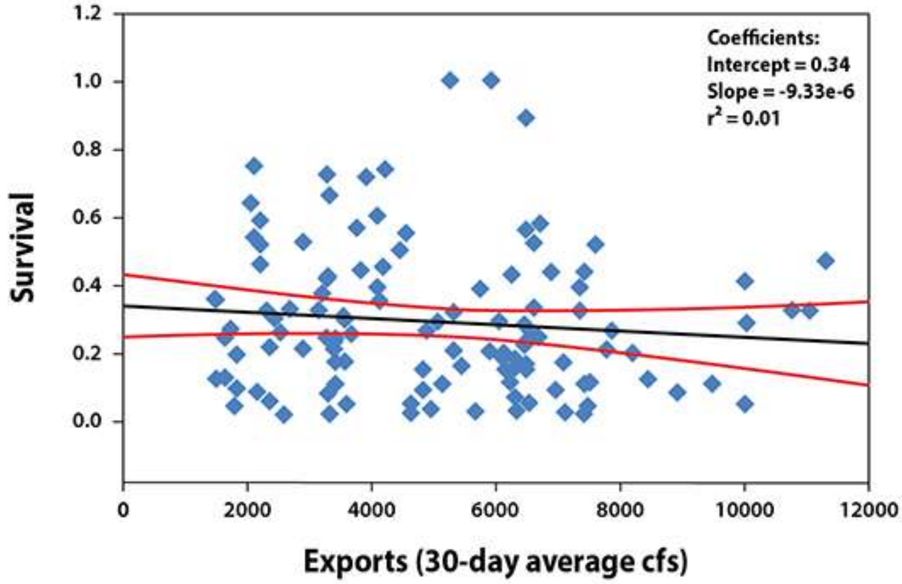

Figure 7-8. Relationship between SWP and CVP exports (30-day average) and Delta salmon survival (1980-2001).

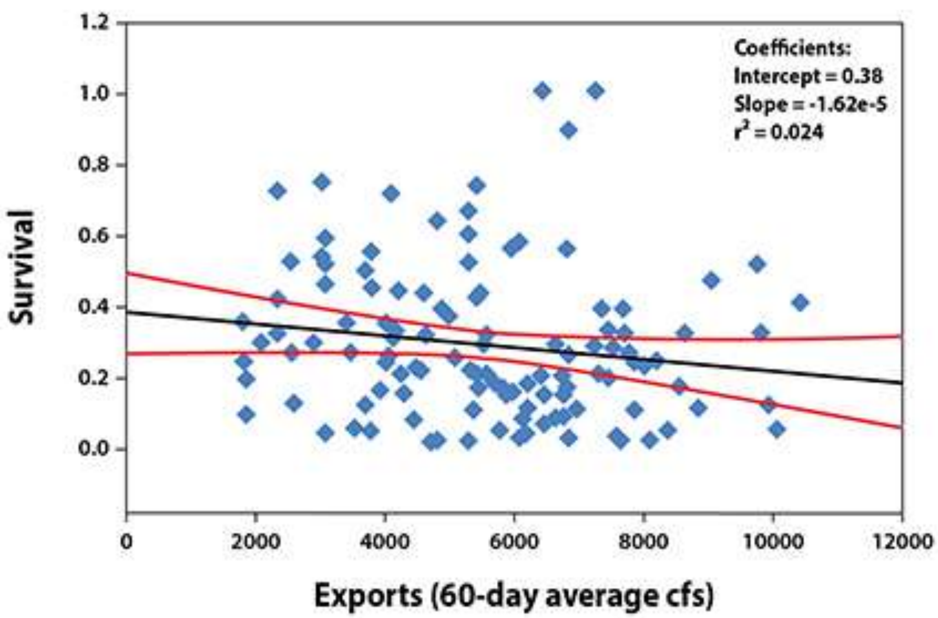

Figure 7-9. Relationship between SWP and CVP exports (60-day average) and Delta salmon survival (1980-2001).

The relationship between juvenile salmon survival in the Delta and combined SWP and CVP export rates was not statistically significant for either the 30-day average export rate (p=0.27) or the 60-day average export rate (p=0.1). Results of these analyses show that SWP and CVP exports, overall, are a small incremental factor affecting survival of juvenile salmon and that regulating exports would not have a strong predictive effect on total survival of juvenile salmon within the Delta.

7.1.1.4 River Flow Rates and Salmon Survival

Results of the USFWS CWT survival studies were also used to explore the interrelationship, if any, between juvenile salmon survival and general environmental factors, such as Sacramento River flow, Delta inflow and Delta outflow. Results of our analyses showed similar relationships between Delta survival and Sacramento River flow, Delta inflow, and Delta outflow (all were significant at $p<0.001$) for both the 30-day and 60-day averaging periods. (Because Sacramento River flow, Delta inflow, and Delta outflow were all found to be autocorrelated, only Sacramento River results are presented in the following analyses).

For example, Figures 7-10 and 7-11 show the relationship between juvenile salmon survival and average Sacramento River flows (cfs) 30 and 60 days prior to the date of last recapture. Although these relationships show a statistically significant increasing trend in survival as river flow increases ($p <0.001$ for both the 30-day and 60-day average flow rates) during the emigration period, the relationships are characterized by high variability (low r^2 values for the regression analyses; r^2=0.18 for the 30-day average flow and r^2=0.17 for the 60-day average flow).

It has been hypothesized that juvenile salmon migrate downstream at a faster rate when Sacramento River flows are higher. A faster rate of downstream migration in response to higher river flows would be expected to reduce the time during which juvenile salmon are vulnerable to predation mortality. *Results of the analysis of CWT salmon released into the upper Sacramento River, however, did not detect any relationship between juvenile transit rate as a function of average Sacramento River flow over either a 30-day (Figure 7-12) or 60-day (Figure 7-13) period. Instead, the data showed that increasing Sacramento River flow does not result in increased salmon migration rates through the river and Delta*. Results of acoustic tag studies conducted by Michel (2010) suggest that there are differences in reach-specific migration rates (Figure 7-3) that could not be detected based on analysis of the CWT releases. Analysis of the CWT study results also showed an increasing trend in juvenile salmon survival as a function of fish size (Figure 7-14). These results are consistent with other studies that show increased juvenile salmonid survival as the fish grow larger (Reisenbichler *et al.* 1981).

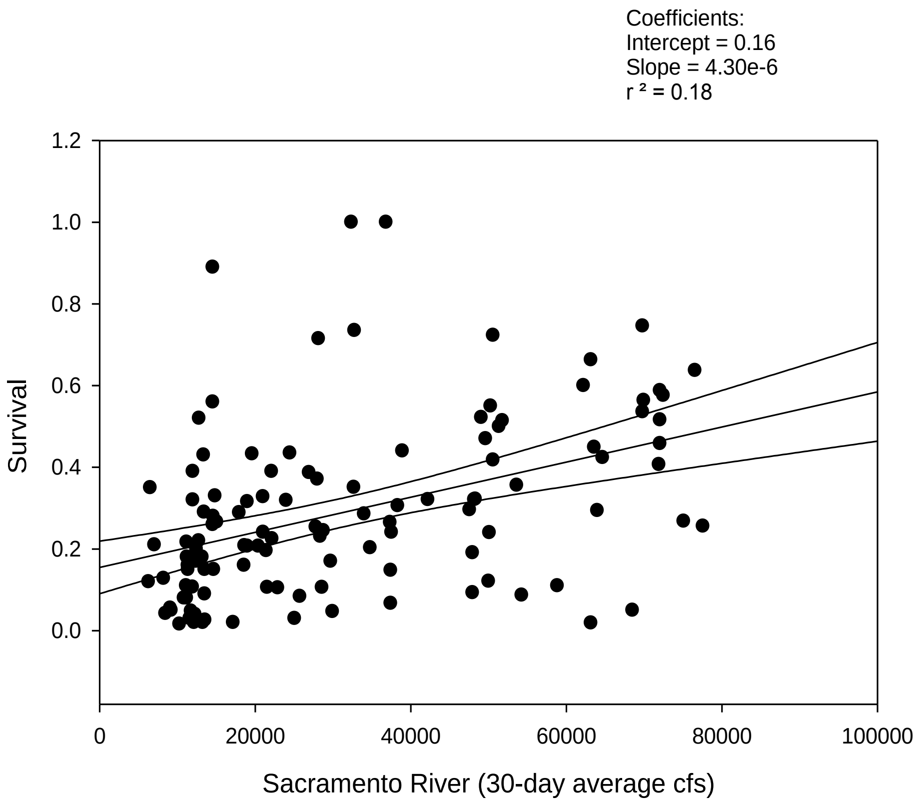

Figure 7-10. Relationship between Sacramento River flow (30-day average) and Delta salmon survival (1980-2001).

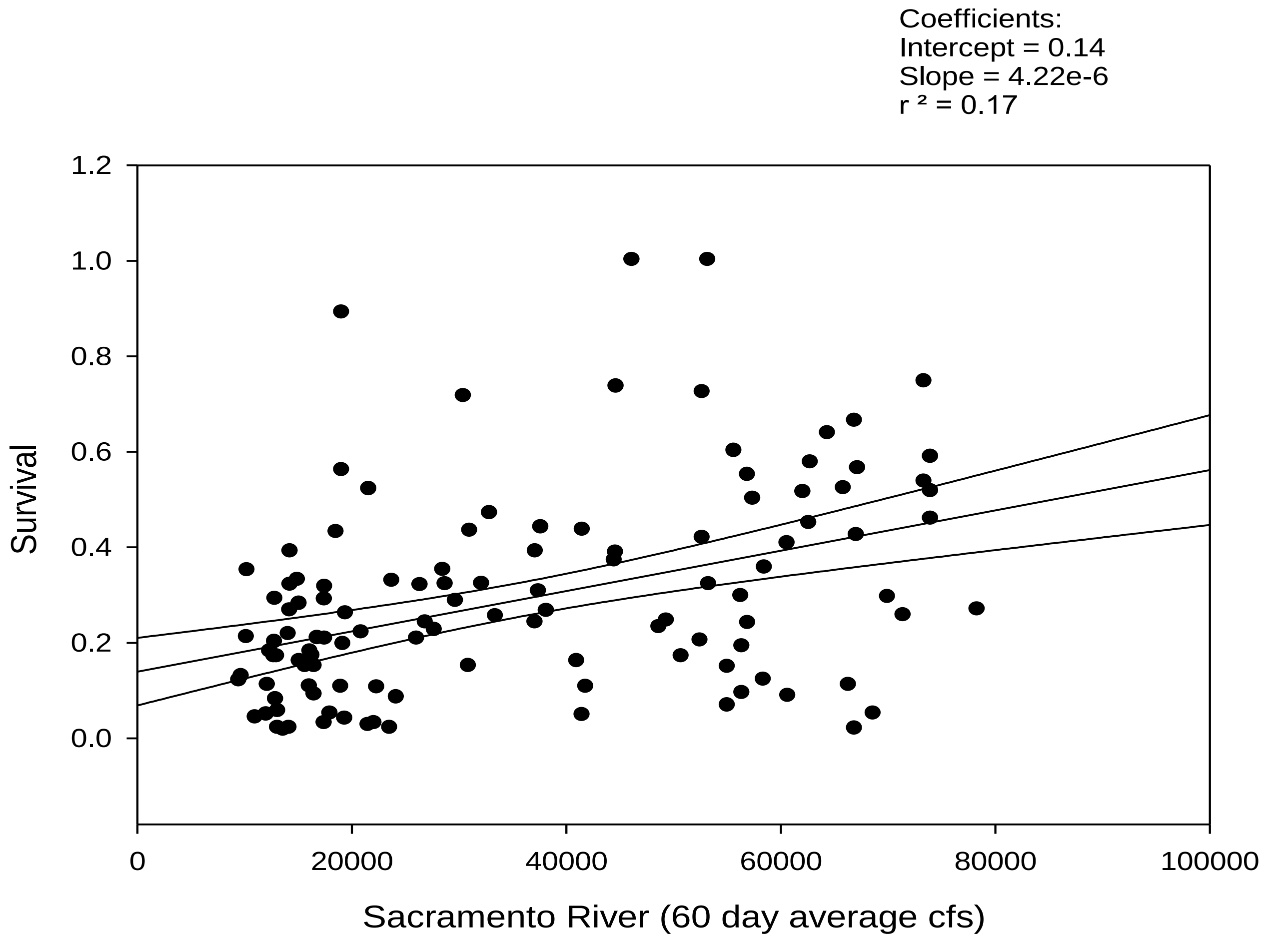

Figure 7-11. Relationship between Sacramento River flow (60-day average) and Delta salmon survival (1980-2001).

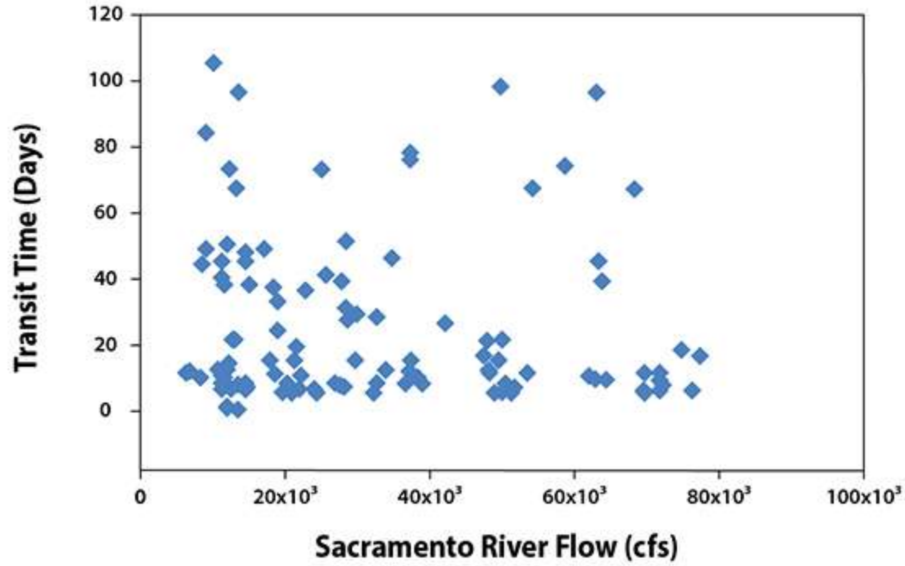

Figure 7-12. Relationship between Sacramento River flow (30-day average) and salmon transit time (1980-2001).

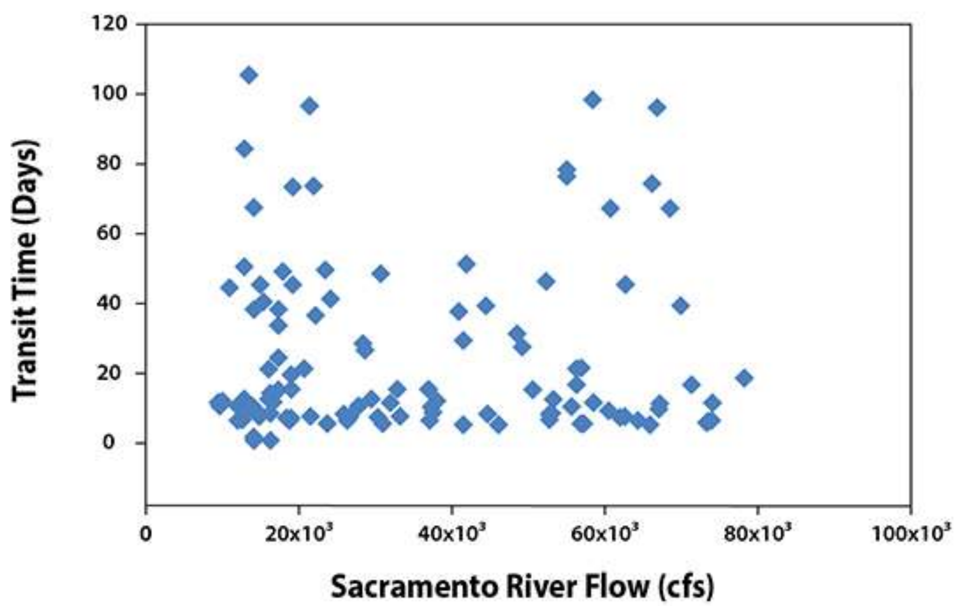

Figure 7-13. Relationship between Sacramento River flow (60-day average) and salmon transit time (1980-2001).

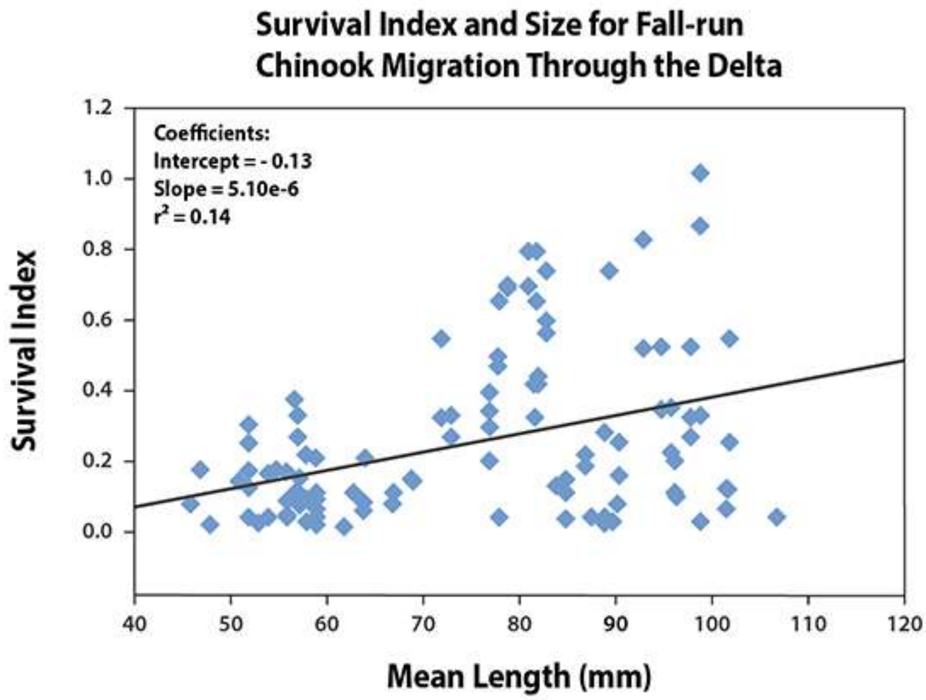

Figure 7-14. Relationship between salmon length at release and survival (1980-2001).

7.1.1.4.1 Multiple Linear Regression Analyses

A multiple linear regression analysis was used to examine the relative contribution of river and Delta flows and SWP and CVP export rates on observed juvenile salmon survival reflected in the USFWS CWT survival studies. Multiple regression analyses allow the statistical determination of the incremental contribution of various factors included in the analysis (some factors such as Delta Cross Channel gate operations, seasonal water temperature, fish health, etc. were not included in the regression analysis; variables included in the analysis were the percentage of tagged fish recaptured at the SWP and CVP salvage facilities, average length of salmon in each release group, Sacramento River flow, and combined SWP and CVP export rate) on observed total Delta survival (as estimated based on USFWS recaptures at Chipps Island).

The multiple regression analyses showed a statistically significant relationship between salmon survival and both fish length and Sacramento River flow. Results of the multiple regression analysis using the 30-day average river flow and export rates showed that the relationship between total Delta survival was significantly related to fish length ($p<0.001$) and Sacramento River flow ($p=0.003$), but not significantly related to either combined SWP and CVP export rate ($p=0.39$) or the percentage of fish salvaged ($p=0.95$). The overall relationship had a relatively low correlation coefficient ($r^2 = 0.29$). The statistical results showed a weak positive relationship between survival and both fish length and river flow, no significant relationship with SWP and CVP exports, and were characterized by high variation and low certainty.

The same analysis was undertaken using a 60-day period and produced similar results. The multiple regression analysis using the 60-day average Sacramento River flow and SWP and CVP combined export rate showed that total Delta survival was significantly related to fish length ($p<0.001$) and Sacramento River flow ($p=0.001$), but was not significantly related to either combined SWP and CVP export rate (p = 0.27) or the percentage of fish salvaged (p = 0.67). The overall relationship between Sacramento River flow and combined Project export rates had a relatively low correlation coefficient ($r^2 = 0.31$).

Results of our analyses were consistent in showing that total Delta survival of juvenile Chinook salmon during emigration through the Sacramento River and Delta was related to both fish size (larger juvenile salmon typically have higher survival rates) and Sacramento River flows (survival rates were higher at higher flows), but were not significantly related to either the percentage of the tag group salvaged at the SWP and CVP export facilities (direct loses) or combined SWP and CVP export rates (indirect effect).

The USFWS CWT mark-recapture studies provide useful and important information regarding the survival of juvenile Chinook salmon migrating through the lower Sacramento River and Delta. The studies have limitations in that capture efficiency varies within and among years in sampling at Chipps Island based on fish size, Delta outflow, and other factors. In addition, sampling at one location, such as Chipps Island, does not provide fine-grained resolution regarding salmonid migration pathways, the duration of migration through various reaches of the river and Delta, and the mortality rate within various reaches. Sampling at a single location also leads to a low probability of detection, particularly for larger juveniles that may avoid capture in conventional trawl sampling. To address many of these issues NMFS, the University of California, the U.S. Army Corps of Engineers, DWR, and others have recently implemented a large-scale acoustic tagging program to investigate salmonid migration patterns, pathways, rates, and mortality within the Sacramento River and Delta. Results of this acoustic tagging program are expected to provide improved understanding of the relationships between river and Delta flows, exports, and other factors on survival of juvenile salmon and steelhead (Klimley *et al.* 2012).

7.1.1.5 2012 JSATS Study

To address the above-described concerns and to provide more detailed information on the movement patterns, behavior, and survival of juvenile salmon, NMFS, UC Davis, Cramer Fish Sciences, DWR, and the USFWS are currently implementing an expanded acoustic tagging study (Hayes 2012). A pilot study using the Juvenile Salmon Acoustic Telemetry System (JSATS) to evaluate Sacramento River Chinook salmon emigrants was conducted during the spring of 2012. An array of 54 receivers was deployed from Battle Creek on the upper Sacramento and the Feather River to the Golden Gate in April 2012. Juvenile fall-run (410 fish) and spring-run (139 fish) Chinook salmon from the Coleman and Feather River hatcheries were tagged and released as part of various experiments. The juvenile salmon used in this pilot study ranged in length from 76-130 mm, thus demonstrating that acoustic tags can be successfully used to monitor movement and survival of smaller juvenile salmon (Hayes 2012). Results of the 2012 pilot study are not yet available but will be used in refining the experimental design for a larger study planned for 2013 (Hayes 2012).

The 2013 acoustic tag study will be designed to track the movement and survival of juvenile winter-run and spring-run Chinook produced in hatcheries, as well as wild fall-run and spring–run juvenile Chinook collected from Deer and Mill creeks. Beginning in the fall of 2012 and continuing through spring 2015, the team will work to (1) install an array of acoustic tag receivers throughout the Sacramento Basin (approximately 100 receivers), (2) conduct tagging and release efforts on roughly 1000 to 1500 acoustically tagged juvenile salmonids per year, (3) manage a joint data base on all data and (4) conduct laboratory experiments regarding tagging effects on fish survival. The release sites and receiver locations for the expanded acoustic study are shown in Figure 7-15. Data to be collected from these new acoustic tag studies will significantly advance the scientific understanding of juvenile salmon migration on the Sacramento River, inform future management decisions, and address a number of areas of uncertainty. Data from similar acoustic tag studies to be conducted on juvenile steelhead as part of the Six Year study on the San Joaquin River are also expected to substantially advance our understanding of salmonid biology in the Central Valley.

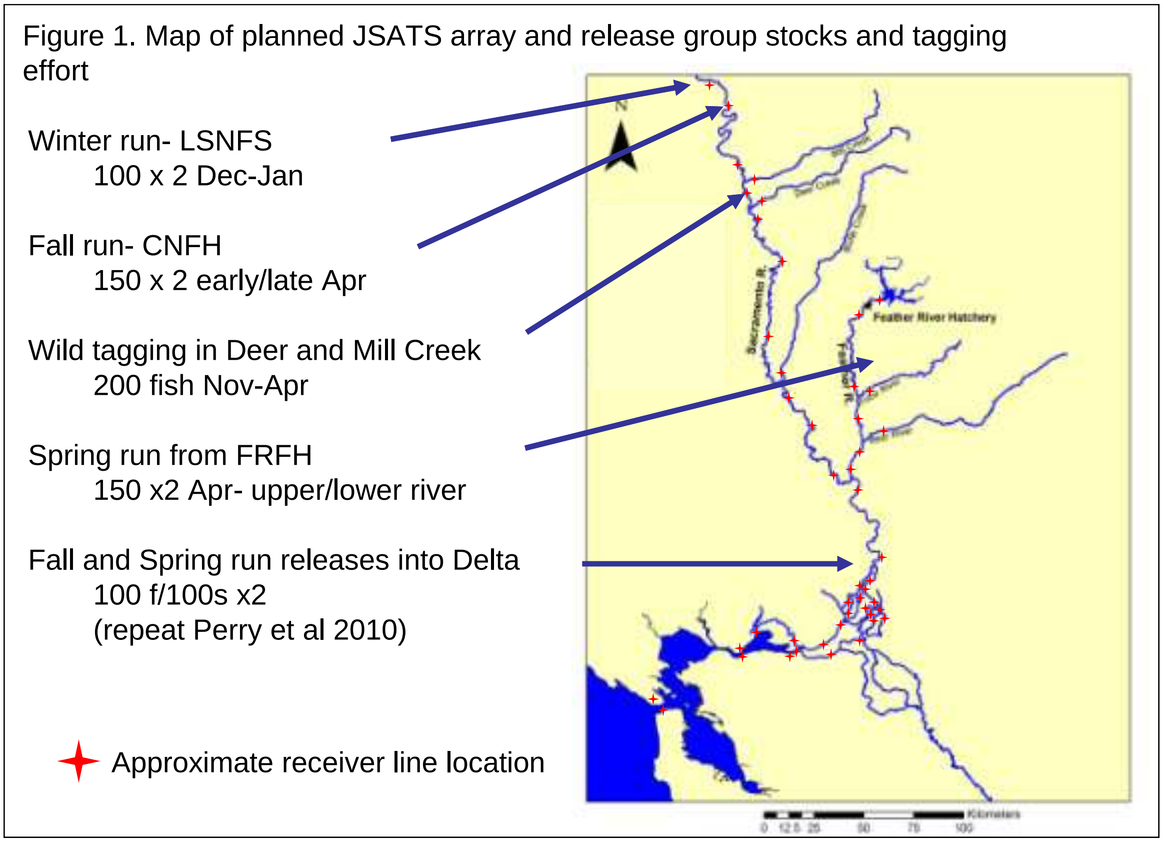

Figure 7-15. Map of the study area for acoustic tracking of hatchery and wild juvenile salmon on the Sacramento River, Delta, and estuary (Source: Hayes 2012).

7.1.1.6 Non-Physical Barrier at Georgiana Slough

Results of survival studies using both CWT and acoustically tagged juvenile salmon (Brandes and McLain 2001, Perry 2010) suggest that juvenile salmon may experience greater mortality if they migrate from the Sacramento River into the interior Delta through Georgiana Slough. Georgiana Slough (Figure 7-16) is a natural channel that meets the Sacramento River near Walnut Grove. It has been hypothesized that the increased juvenile salmon mortality observed for those fish that enter the slough results from their longer migration pathway and resulting increased exposure to water diversions and predators within the Delta. Georgiana Slough serves as an important channel for recreational boating. Sacramento River water flowing into the channel improves interior Delta water quality. Therefore, blocking the slough entirely for the purpose of guiding juvenile salmon down the mainstream Sacramento River is not feasible. As an alternative to a physical barrier (e.g., radial gates such as those used at the Delta Cross Channel or a rock barrier such as that used at the Head of Old River), DWR investigated the use of a non-physical barrier at Georgiana Slough.

Combining underwater light, sound, and air bubbles the non-physical barrier discourages salmon from entering the interior Delta. The non-physical barrier was installed and tested in the Sacramento

River at Georgiana Slough during the winter and spring of 2011 and 2012 (Figure 7-17; DWR 2012). Acoustically tagged late fall-run Chinook salmon produced at the Coleman Hatchery (and juvenile steelhead in 2012) were released into the Sacramento River immediately downstream of the confluence of Steamboat Slough, approximately 6 miles upstream of Georgiana Slough (Figure 7-18) to test the barrier's efficacy. Small groups of tagged fish were released at intervals throughout the day and night to represent various sunlight and tidal conditions. The barrier was cycled on and off during the tests. Tagged salmon were monitored using a three-dimensional acoustic tracking network (Figure 7-19) to determine their movement, behavior, and response, as well as the barrier's guidance efficiency. Analyzing the three-dimensional "tracks" left by each tagged fish, predation estimates could also be made as juvenile salmon pass through the study area. The results conducted in 2011 are reported by DWR (2012). The 2012 results are currently being reviewed.

The Georgiana Slough studies provide another example of the recent application of sophisticated acoustic tagging studies to investigate the response of juvenile salmon to flow splits, tidal currents, and water velocities, as well as the species' behavioral response to environmental conditions within the Delta. The studies also serve as a powerful tool for assessing the effectiveness of a potential non-physical barrier management action for protecting and improving the survival of juvenile salmonids as they migrate downstream through the Sacramento River and Delta. Through the application of experiments and improving technology, substantial strides have been made in understanding salmon biology in the Delta over the past 5 years. Expanded studies are currently being planned and implemented that will further contribute to the body of scientific information available for making management decisions.

Figure 7-16. **Delta map showing Georgiana Slough (DWR 2012).**

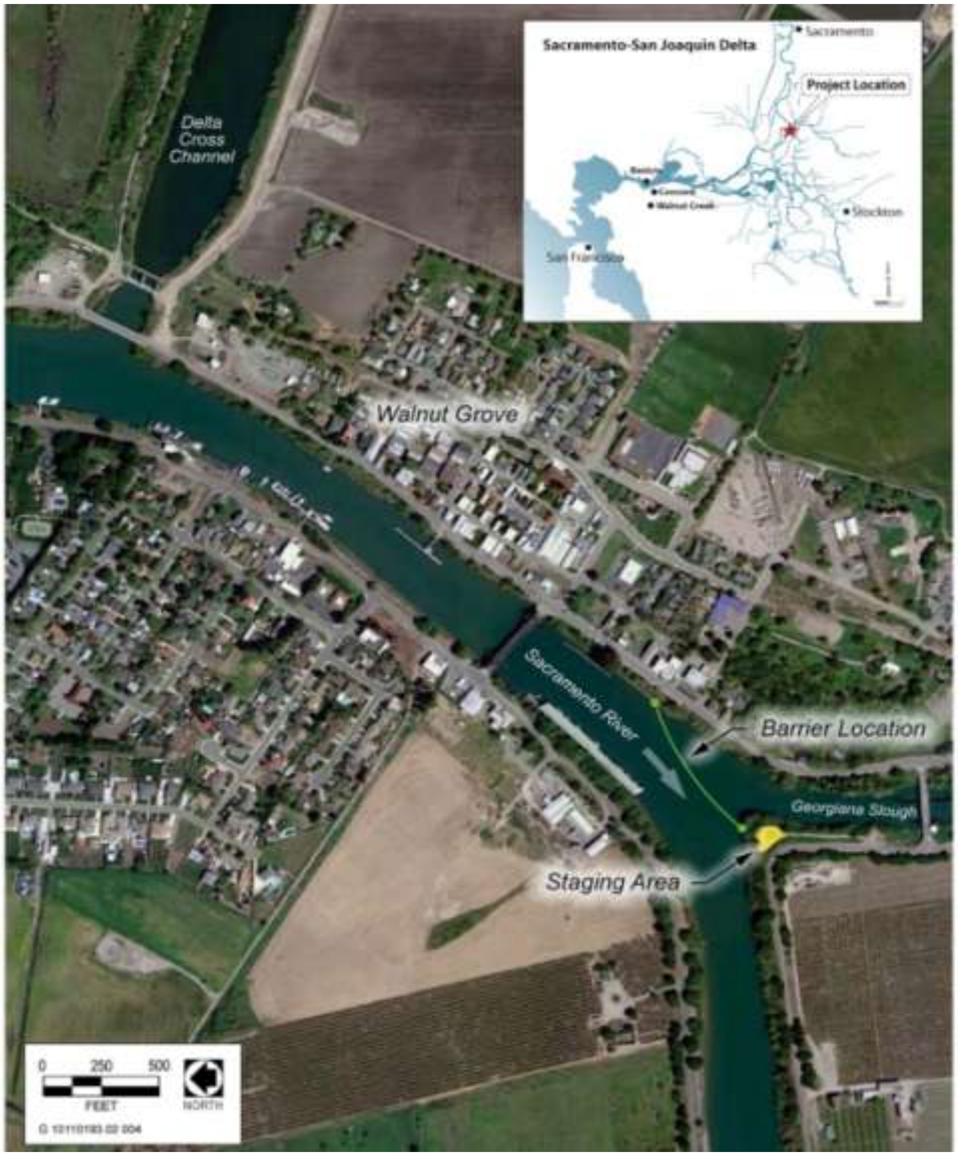

Figure 7-17. Sacramento River in the vicinity of Walnut Grove showing the location of the non-physical barrier tested in 2011 and 2012 (DWR 2012).

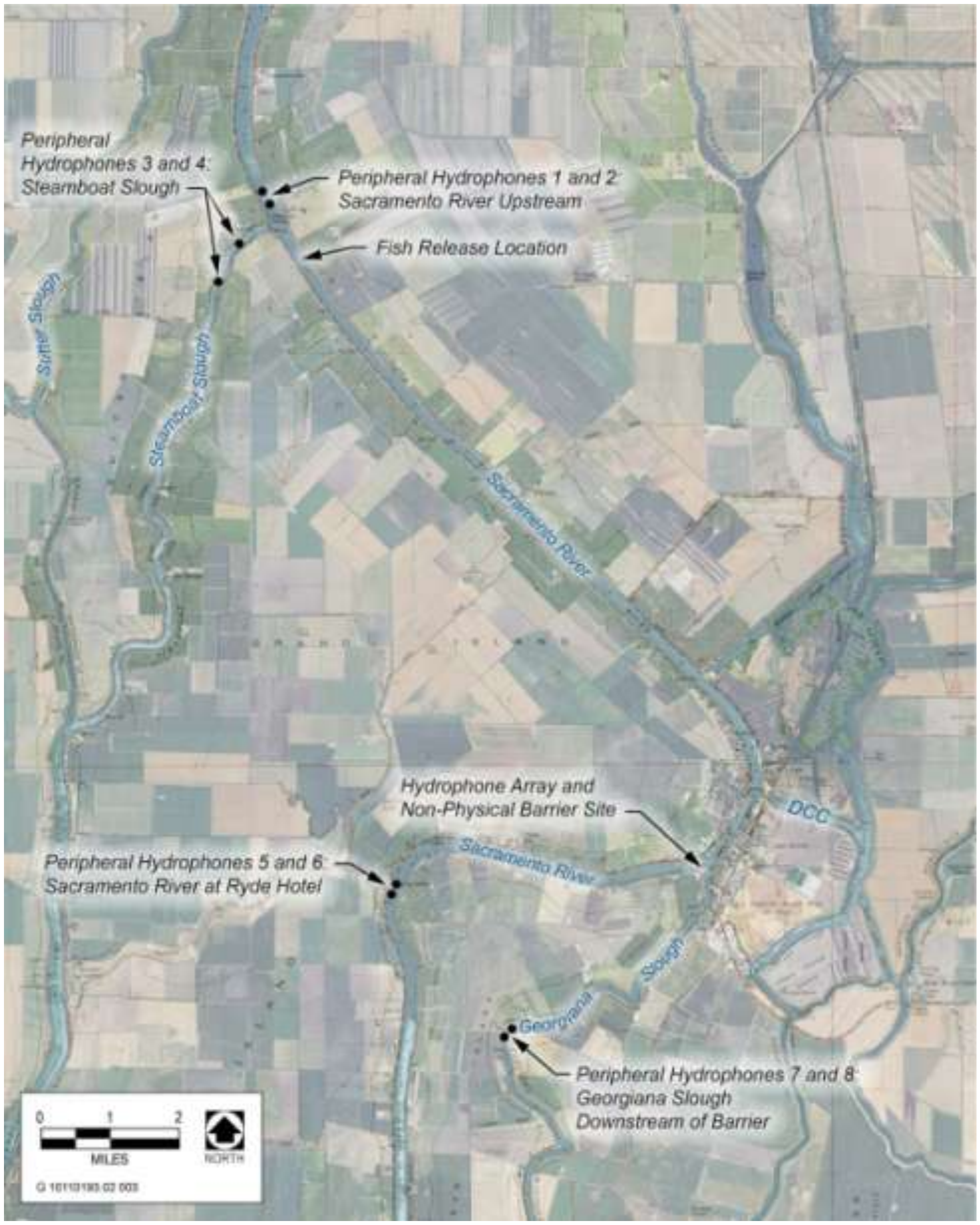

Figure 7-18. Map showing the basic experimental design for the 2011 and 2012 Georgiana Slough non-physical barrier acoustic tag tests (DWR 2012).

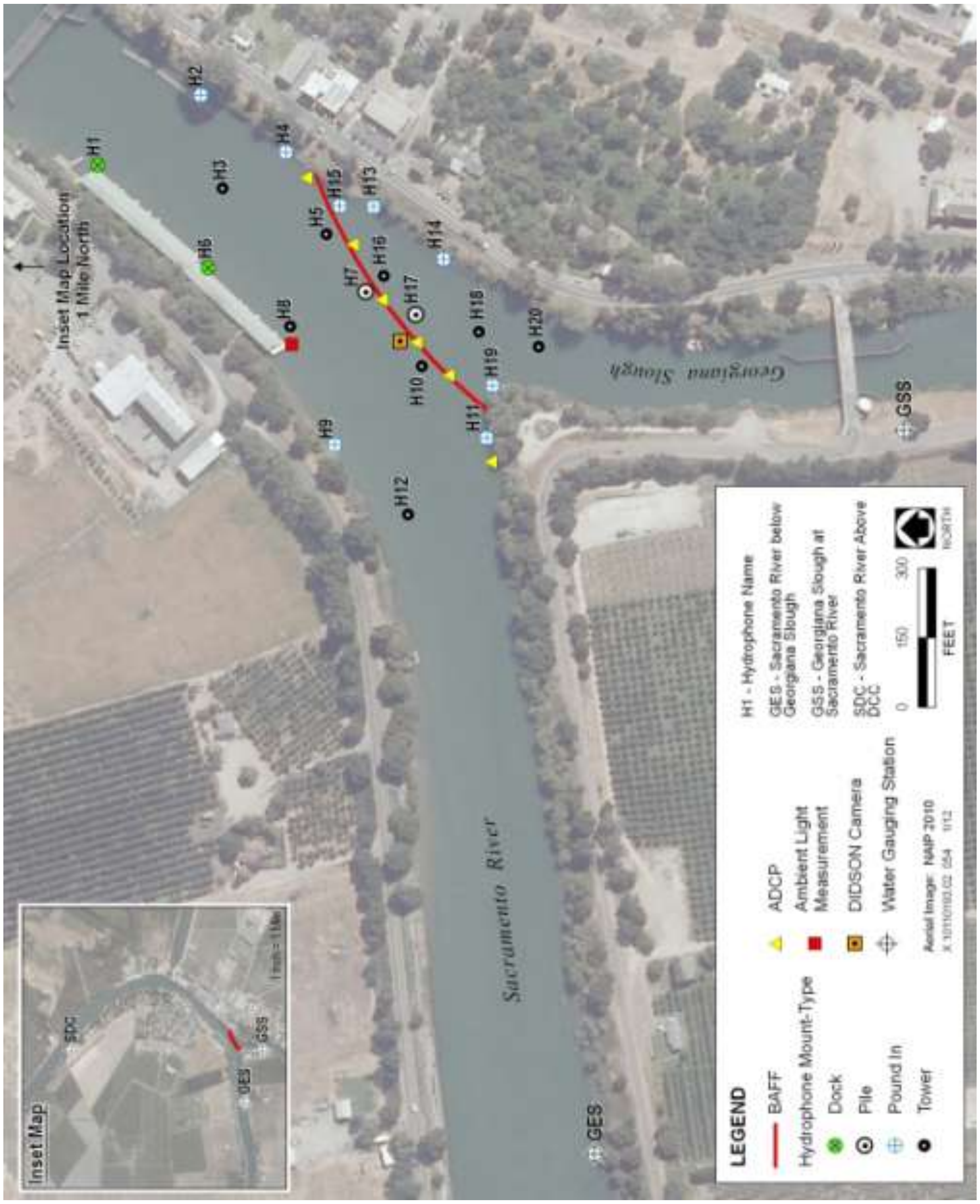

Figure 7-19. Deployment of 3-dinensional acoustic tag detector array associated with the Georgiana Slough non-physical barrier tests (DWR 2012).

8 San Joaquin River System

8.1 Background on Salmonid Use of San Joaquin River System

The primary San Joaquin River tributaries—the Merced, Tuolumne, and Stanislaus rivers—support spawning and rearing of fall-run Chinook salmon. These tributaries also support small populations of steelhead, as well as resident rainbow trout and other fish species. A fish hatchery located on the Merced River produces juvenile fall-run Chinook salmon. Restoration efforts are underway to re-establish self-sustaining, naturally reproducing populations of spring-run and fall-run Chinook salmon on the mainstem San Joaquin River downstream of Friant Dam (USBR 2012).

The San Joaquin River basin fall-run Chinook salmon population has been characterized by high variability in adult returns to the river system (Figure 8-1) that reflect a pattern in abundance thought in part to reflect cyclical ocean rearing conditions (e.g., Pacific Decadal Oscillation) although no detailed analyses have been developed to rigorously test the potential relationship between ocean conditions and adult salmon returns to the San Joaquin River basin. In addition, the San Joaquin River tributaries and mainstem river are characterized by substantially less freshwater runoff when compared to the Sacramento River basin, which is reflected in lower instream flows and frequently greater seasonal water temperatures that affect habitat quality and availability, reproductive success, survival, and overall abundance of Chinook salmon and steelhead within the San Joaquin basin. Striped bass and other predatory fish are common in the lower reaches of the river, particularly in the spring months when juvenile salmonids are migrating downstream through these reaches.

The lower San Joaquin River channels contain little to no seasonally inundated floodplain at typical late winter and spring flow levels. With adequate flows, these areas would otherwise serve as habitat and provide increased organic material and food supplies to juvenile rearing salmon and other aquatic species. Historically, an area of depressed dissolved oxygen in the vicinity of the Stockton shipping channel contributed to decreased habitat quality in the lower reach of the river. Efforts to provide additional aeration have led to recent improvements in dissolved oxygen concentrations in the lower river (Newcomb 2010).

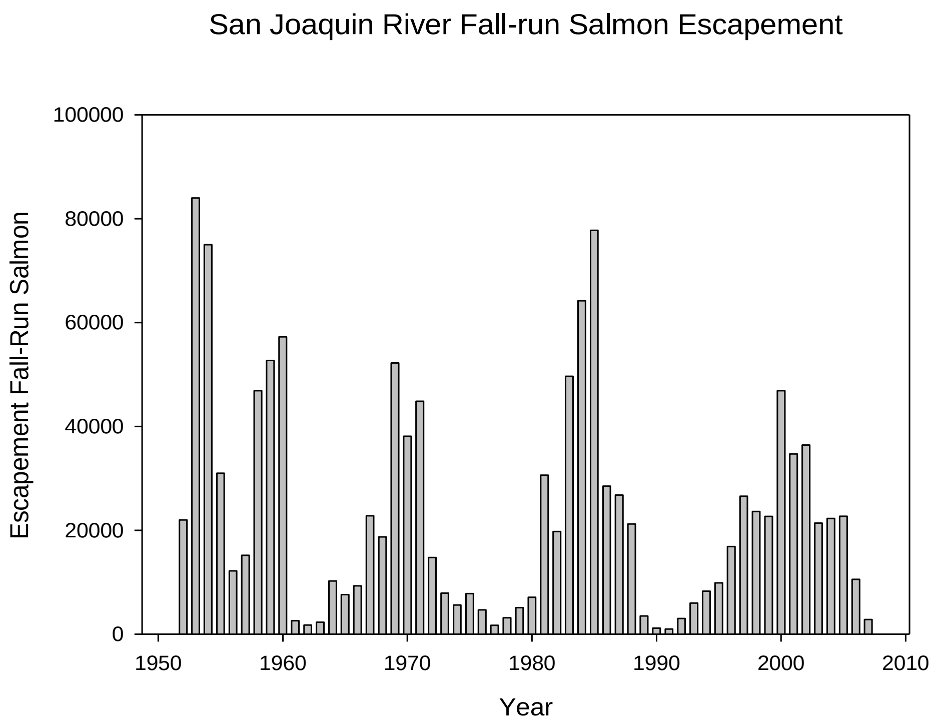

Figure 8-1. **Adult fall-run Chinook salmon escapement to the San Joaquin River basin (Source: GranTab 2011).**

8.1.1 Head of Old River

The Head of Old River is a channel that diverges from the lower San Joaquin River downstream of Mossdale. Old River can serve as a pathway for juvenile salmonids to migrate from the mainstem river into the interior Delta. Juvenile salmon mortality rates in the interior Delta are generally thought to be higher than for salmon in the mainstem San Joaquin River based on results of CWT survival studies.

CWT survival studies conducted using juvenile fall-run Chinook salmon released into the lower San Joaquin River show greater salmon survival when the temporary rock barrier is installed at the Head of Old River during the spring (SJRGA 2006). From 2000 to 2004 and in 2007, a physical (rock) barrier was installed at the Head of Old River (HORB) when river flow was less than 7,000 cfs to block the movement of salmon smolts into Old River and to encourage the fish to continue their migration down the San Joaquin River's mainstem. High flows in 2005 and 2006 prohibited installation of the barrier. Due to concerns about delta smelt protection expressed by the Delta Smelt Working Group and as a result of orders issued by the Court in *NRDC v. Kempthorne*, the HORB physical barrier has not been installed since 2008.

In 2009 DWR, in cooperation with Reclamation, began testing a non-physical behavior barrier at the Head of Old River. The non-physical barrier included a combination of light, sound, and air bubble curtains to guide juvenile salmon away from the Head of Old River and to encourage their downstream migration in the mainstem lower San Joaquin River. Installing the non-physical (bubble) barrier was premised, in part, on extensive laboratory and field testing of such barriers over the past several decades.

San Joaquin-Old River non-physical barrier field testing occurred in the spring (April-May) of 2009 and 2010 (Bowen *et al.* 2009, Bowen and Bark 2010). The bubble barrier's effectiveness in guiding juvenile salmon away from entering Old River was analyzed based on a series of comparative tests with the barrier on and off. Preliminary results in 2009 show that the barrier was approximately 80 percent effective in deterring tagged juvenile salmon from entering Old River. (Figure 8-2 shows an example of an acoustically tagged salmon that was effectively guided downstream into the mainstem San Joaquin River by the barrier). The results also showed that predation on juvenile salmon within a scour hole in the San Joaquin River immediately downstream of the barrier altered salmon behavior and survival (Figure 8-3 shows an example of a juvenile Chinook salmon that was preyed on in the vicinity of the barrier).

The non-physical barrier data show that the barrier can provoke a strong behavioral response by juvenile salmon that may substantially reduce juvenile salmon migration into Old River. Testing the non-physical bubble barrier in spring 2009 and 2010 showed high guidance efficiency that could potentially be used to reduce the risk of juvenile salmon migrating into Old River and, thereby, reduce the risk of entrainment and salvage losses. The 2009 and 2010 studies also showed high predation rates on juvenile salmon in the area adjacent to and immediately downstream of the barrier.

The 2009 and 2010 bubble barrier tests provide strong evidence that a non-physical barrier, although requiring further testing, has the potential to reduce the vulnerability of Chinook salmon to entrainment losses and to increase juvenile survival for Chinook salmon migrating downstream in the lower San Joaquin River.

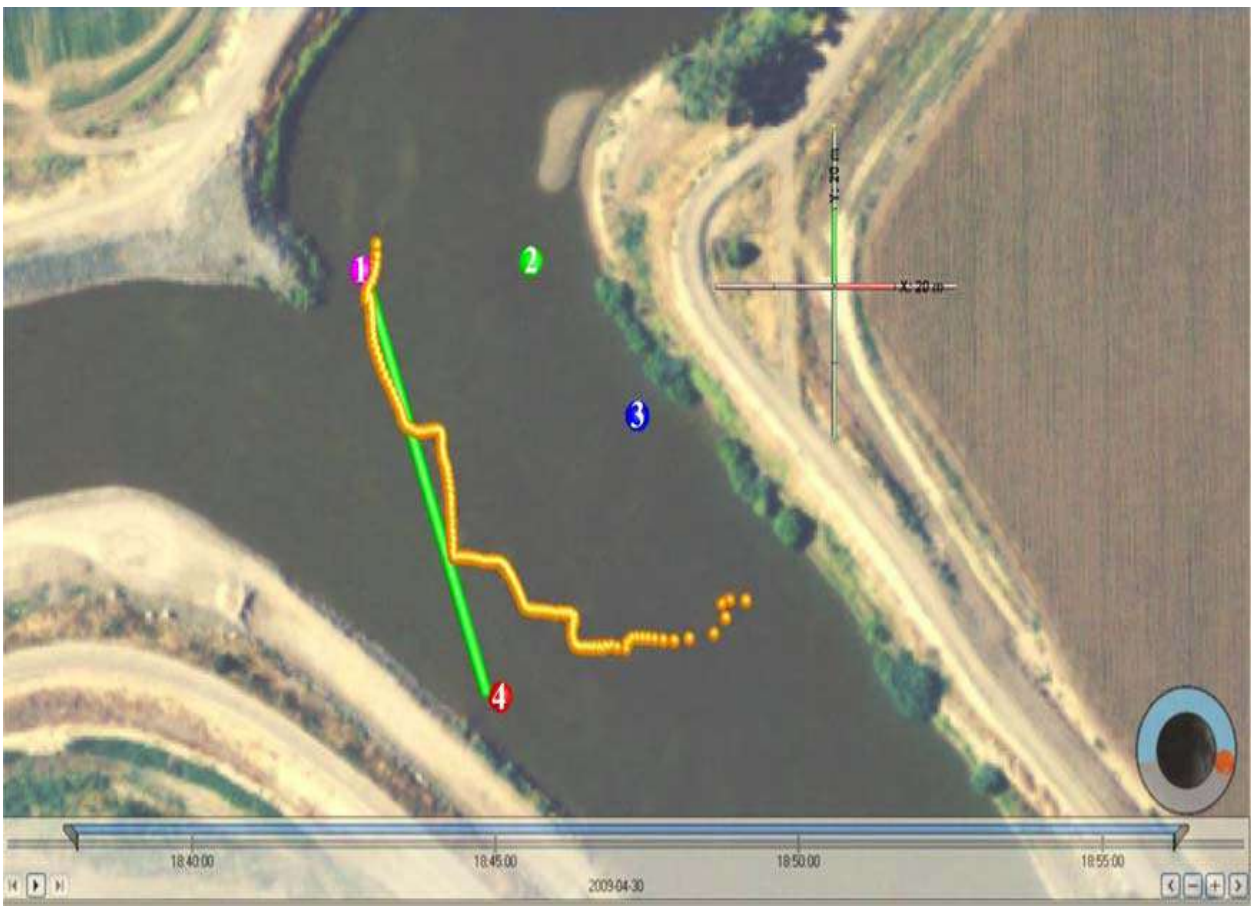

Figure 8-2. Acoustic tag tracking results for a juvenile Chinook salmon (yellow track) that was effectively guided downstream by the non-physical barrier (green line) at the Head of Old River (Source Bowen *et al.* 2009).

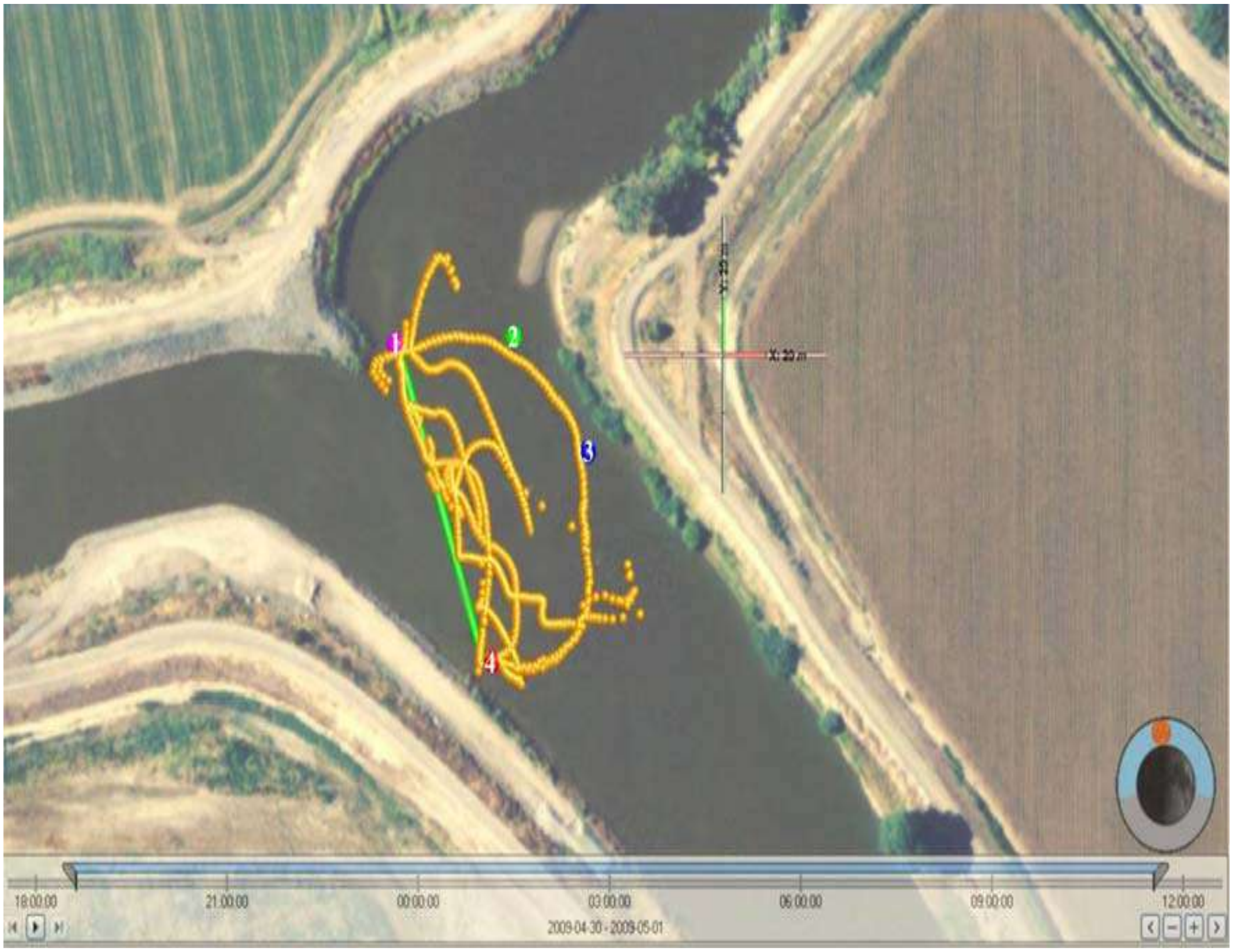

Figure 8-3. Acoustic tag tracking results for a juvenile Chinook salmon (yellow track) that was preyed upon in the vicinity of the non-physical barrier (green line) at the Head of Old River (Source Bowen *et al.* 2009).

8.1.2 VAMP Studies: Juvenile Chinook Salmon Survival

The 1995 SWRCB Water Quality Control Plan (D-1641) established the VAMP to investigate the effects of San Joaquin River flows at Vernalis, SWP and CVP exports, and the installation of the Head of Old River Barrier on juvenile salmonid survival. The studies, which became known as "The San Joaquin River Agreement" and VAMP, are integral parts of D-1641 and served as the cornerstones of a commitment to implement the Water Quality Control Plan for the lower San Joaquin River and the San Francisco Bay-Delta Estuary. The VAMP experimental design was developed to address concerns with earlier survival studies conducted during periods when river flows were highly variable. Those earlier studies contributed to increased uncertainty about the relationship between river flow and juvenile salmon survival.

The VAMP experiment was initiated in 2000 as a large-scale, long-term (12-year) management program designed to protect and study juvenile Chinook salmon migrating from the San Joaquin River through the Sacramento-San Joaquin Delta. It was also intended as a scientific experiment to determine how salmon survival rates may change in response to alterations in San Joaquin River flows and SWP/CVP exports with the HORB installed.

VAMP's specific experimental objectives included quantification of juvenile salmon smolt survival under a set of six San Joaquin River flow rates (3,200 to 7,000 cfs) and SWP/CVP export rates (1,500 to 3,000 cfs). To achieve these objectives, VAMP provided for a steady pulse flow (target flow) at the Vernalis gauge on the San Joaquin River (upstream of the Delta) during a consecutive 31-day period in the months of April and May, along with a simultaneous reduction in SWP/CVP exports. The specific VAMP target flow and Delta export levels were established based on a forecast of the San Joaquin River flow that would occur during the pulse flow period absent the VAMP (Existing Flow). Any supplemental water (beyond otherwise existing San Joaquin River flows) needed to achieve the VAMP target flows, up to a limit of 110,000 acre-feet, was provided by the San Joaquin River Group Authority member agencies through coordinated operation of dams on the three major San Joaquin River tributaries upstream of Vernalis: the Merced River, the Tuolumne River and the Stanislaus River.

The original experimental design for VAMP also included two mark-recapture studies to be performed each year during the mid-April to mid-May juvenile salmon outmigration period to provide estimates of salmon survival under each of the six sets of VAMP San Joaquin River flow rates and CVP/SWP export rates. Chinook salmon survival indices under each of the experimental conditions were to be calculated based on the numbers of marked salmon released and recaptured in each year. Absolute survival estimates were also to be calculated and used to evaluate relationships between salmon survival and San Joaquin River flow and CVP and SWP exports.

The original VAMP experimental design included multiple release locations (Durham Ferry, Mossdale, and Jersey Point; Figure 8-4), and multiple recapture locations (Antioch, Chipps Island, SWP and CVP salvage operations, and in the ocean fisheries). The use of data collected from multiple release and recapture locations was intended to allow for more thorough evaluation of juvenile Chinook salmon survival (as compared with recapture data based upon one sampling location and/or one series of releases). The VAMP release and recapture locations were consistent from one year to the next, providing a greater opportunity to assess salmon survival over a range of Vernalis flows and SWP/CVP exports, with and without the presence of the HORB. Releases of juvenile salmon smolts at Jersey Point served as a control for recaptures at Antioch and Chipps Island. This allowed for the calculation of survival estimates based on the ratio of survival indices from marked salmon recaptured from upstream (Durham Ferry and Mossdale) and downstream (control release at Jersey Point) releases. The use of ratio estimates as part of the VAMP study design factored out potential differential gear efficiencies at Antioch and Chipps Island within and among years. The studies used CWT juvenile Chinook salmon during the early years of the survival program and acoustically tagged juvenile salmon during later years.

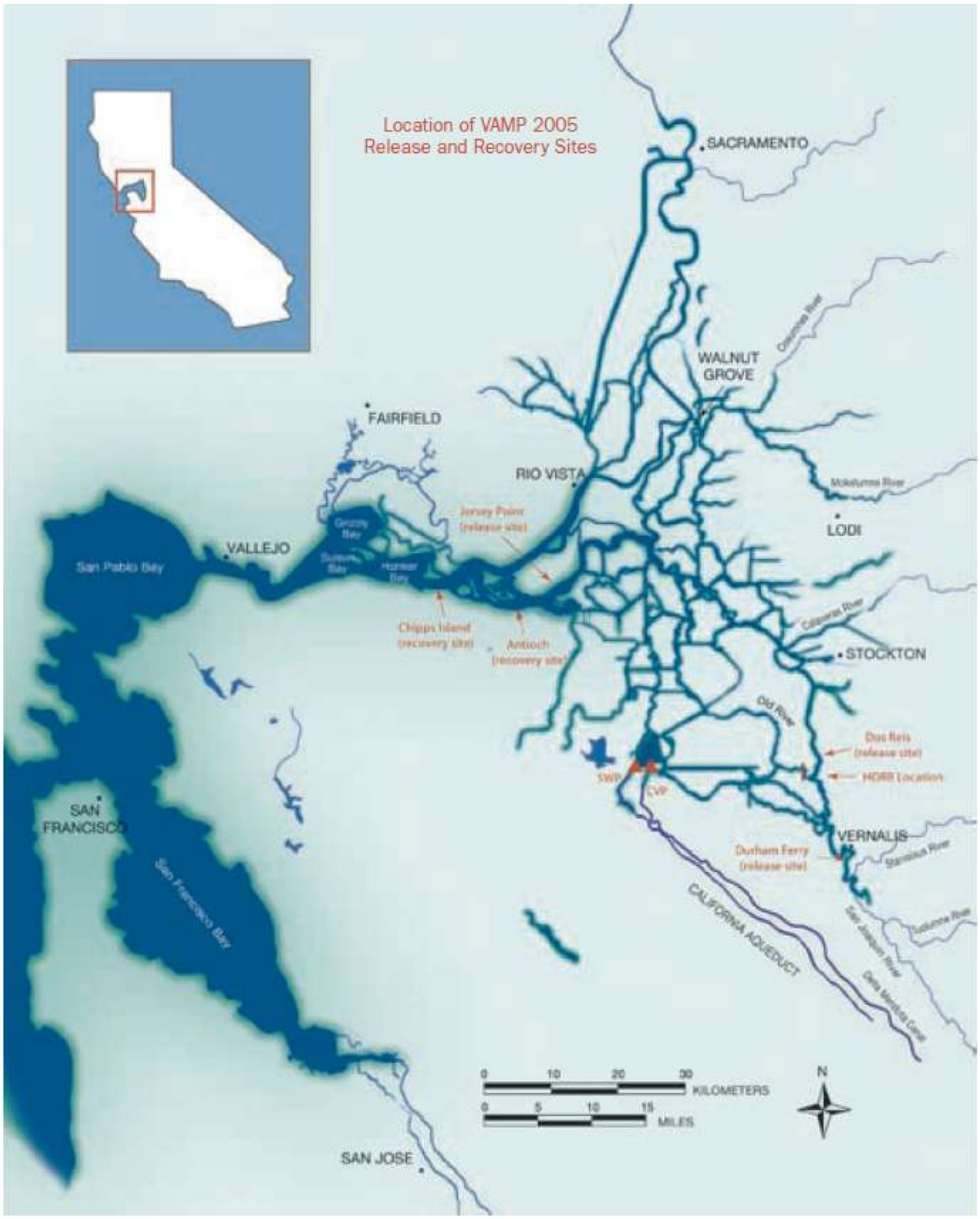

Figure 8-4. Map showing the location of VAMP survival study release and recapture sites for CWT juvenile Chinook salmon.

The VAMP experimental test conditions, namely, flow at Vernalis, SWP/CVP export rates, and the I:E ratio, between April 2000 and May 2010 are summarized in Table 8-1. As reflected in the table, in all years but 2001, the I:E ratio tested rarely exceeded 2:1 by a significant amount (San Joaquin River flows to exports). At no time did the ratio of flows to exports under VAMP exceed 3:1, with the exception of the high flow years (2005 and 2006) when (contrary to the study design) the HORB could not be installed.

Table 8-1. Summary of river flows, export rates, and the ratio of inflow to exports tested as part of VAMP between 2000 and 2010.

Year	Vernalis Flow (cfs)	SWP/CVP Exports (cfs)	San Joaquin River Inflow:Export rate
April 15-May 15, 2000	5,869	2,155	2.7:1
April 15-May 15, 2001	4,224	1,420	3:1
April 15-May 15, 2002	3,301	1,430	2.3:1
April 15-May 15, 2003	3,235	1,446	2.2:1
April 15-May 15, 2004	3,155	1,331	2.4:1
May 1-31, 2005[1]	10,390	2,986	3.4:1
May 1-31, 2006[1]	26,020	1,559/5,748	16.7:1/4.5:1
April 22-May 22, 2007[2]	3,263	1,486	2.2:1
April 22-May 22, 2008[2]	3,163	1,520	2.1:1
April 19-May 19, 2009[2]	2,260	1,990	1.1:1
April 25 – May 25, 2010[2]	5,140	1,520	3.4/1

[1] The HORB was not installed in 2005 and 2006 as a result of high river flow.

[2] The designed CWT survival studies were not conducted in 2007-2011. Studies undertaken in those years were modified to examine species behavior and vulnerability to predation using acoustically tagged juvenile salmon.

Between 2000 and 2006, the full VAMP study plan required the use of 400,000 CWT Chinook, but in several years, the full allocation was not provided due to the limited number of available juvenile fall-run Chinook salmon from the Merced Hatchery and competition with other studies.

During 2007, a sufficient number of test fish were not available from the Merced River Fish Hatchery to permit a CWT study. Instead, an acoustic telemetry monitoring study was performed that year, which used fewer than 1,000 juvenile salmon (this study design continued through 2011). Juvenile Chinook salmon from the Merced River Hatchery were surgically implanted with acoustic transmitters (Figure 6-1) capable of emitting an electronic signal for up to 3 weeks. Chinook salmon survival indices under the experimental conditions using the acoustic-tagged salmon were not possible due to the lack of acoustic receivers at Jersey Point and Chipps Island. However, detailed data were collected regarding salmon smolt behavior and mortality conditions within the south Delta.

8.1.2.1 VAMP Study Results

The VAMP survival studies using CWT juvenile hatchery-raised salmon and conducted between 2000 and 2006 showed the following:

- As a result of hydrologic conditions, the studies conducted reflected San Joaquin River inflow to SWP and CVP exports limited to ratios of approximately 2:1 or greater, rather than the greater range of flow and export conditions anticipated in the original study design;
- The VAMP studies conducted when San Joaquin River flows were less than 7,000 cfs did not test juvenile steelhead survival or river flow to export ratios of 4:1 or more, per the experimental design;

- The studies did not identify a statistically significant relationship between salmon survival and SWP/CVP exports;
- Survival of juvenile salmon during their downstream migration was found to be significantly related to flow levels in the San Joaquin River at Vernalis when the HORB was installed (Figure 8-5). There were substantially lower juvenile salmon survival rates as a function of flow when the HORB was not installed (Figure 8-5);
- The relationship between juvenile salmon survival and the ratio of flow/exports was characterized by high variability (Figure 8-6);
- There was no clear relationship between smolt survival and San Joaquin River flow without the HORB installed within the range of flows actually tested under VAMP. However, an apparent relationship was identified between adult escapement and Vernalis flow during the juvenile migration period 2-1/2 years earlier (Figure 8-7) when examined over a wider range of flow conditions (SJRGA 2006);
- Regressions between survival from Mossdale and Durham Ferry to Jersey Point using Chipps Island, Antioch, and ocean recoveries showed no clear relationship with flow/export ratios within the range of E:I ratios tested under VAMP. However, an apparent relationship was identified between adult escapement and the E:I ratio 2-1/2 years earlier when tested over a wider range of E:I ratios (Figure 8-8); and
- Survival tests conducted when river flow:export rates were greater than 3:1 (2005 and 2006) occurred during high flow conditions in the river that were outside the framework of managed flows included in the VAMP experimental design. High flow conditions in these years also prevented installation of the barrier at the Head of Old River. Because increased river flow was found to be a significant factor affecting juvenile survival in the VAMP studies, the effect of exports under high river flow conditions (i.e., when ratios of flow:export that were greater than 3:1) could not be detected statistically.

Results from the modified VAMP studies of acoustically tagged juvenile salmon conducted from 2007 to 2011 showed:

- Predation is a major source of mortality for juvenile salmon in the lower San Joaquin River and Delta;
- Acoustic tagging offers the opportunity to examine fish behavior and migration within the lower San Joaquin River and Delta; however, the number of fish tagged and monitored in the modified VAMP studies was low, and numerous technical problems emerged while implementing these studies; and

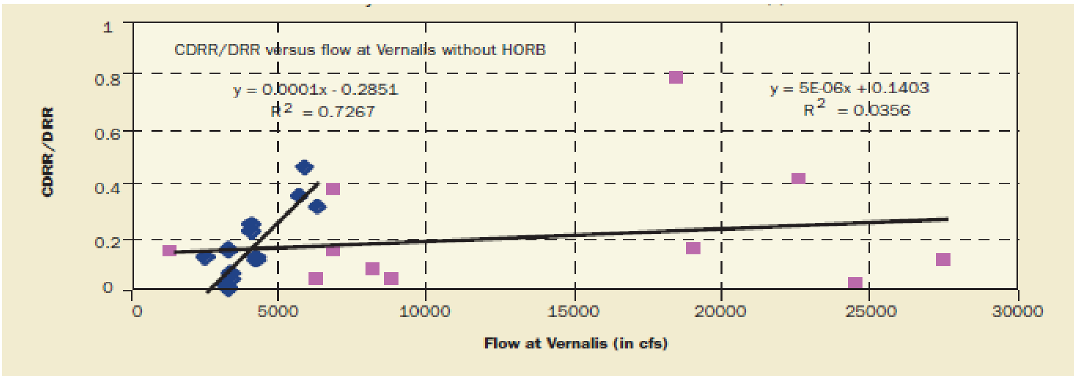

Figure 8-5. **Results of CWT survival studies on the lower San Joaquin River as a function of average flow at Vernalis over a 10-day period after release with and without the Head of Old River Barrier (Source: SJRGA 2006).**

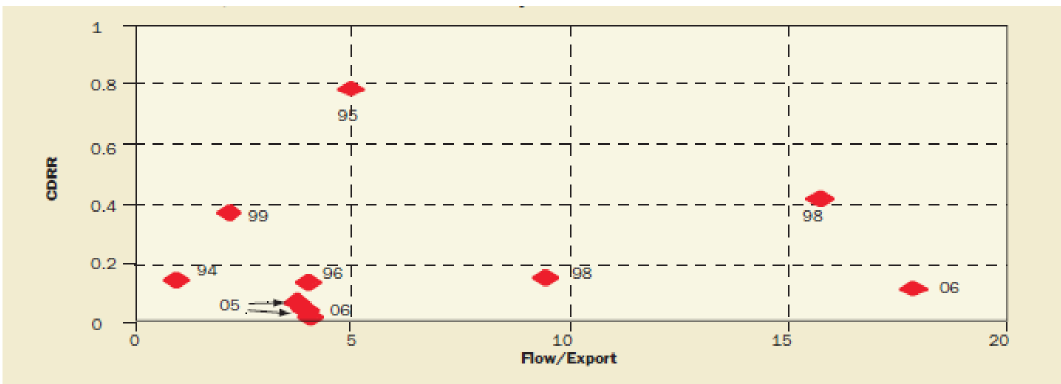

Figure 8-6. **Survival of CWT juvenile Chinook salmon released into the San Joaquin River at Durham Ferry and Mossdale (corrected for Jersey Point controls) as a function of the average Vernalis flow/Export rate over a 10 day period following release without the Head of Old River Barrier (Source: SJRGA 2006).**

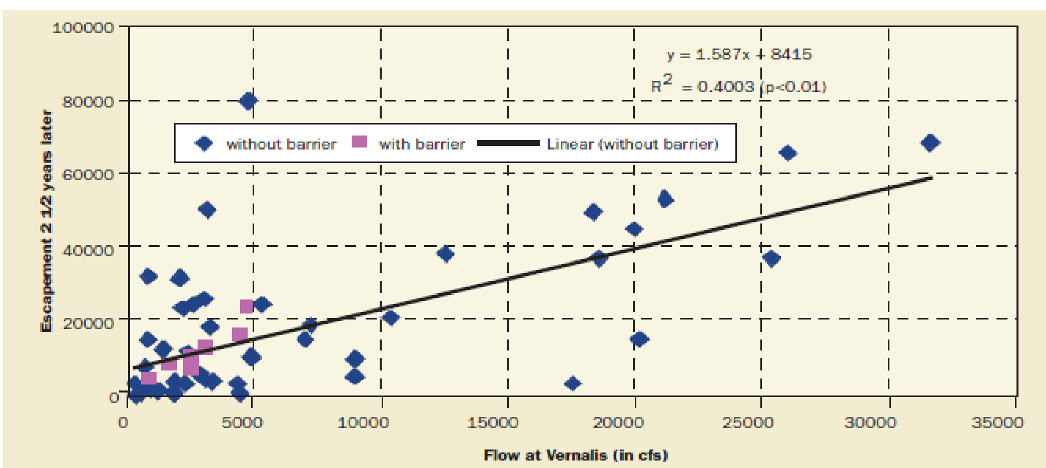

Figure 8-7. **Relationship between adult Chinook salmon escapement and average Vernalis flows 2-1/2 years earlier (Source: SJRGA 2006).**

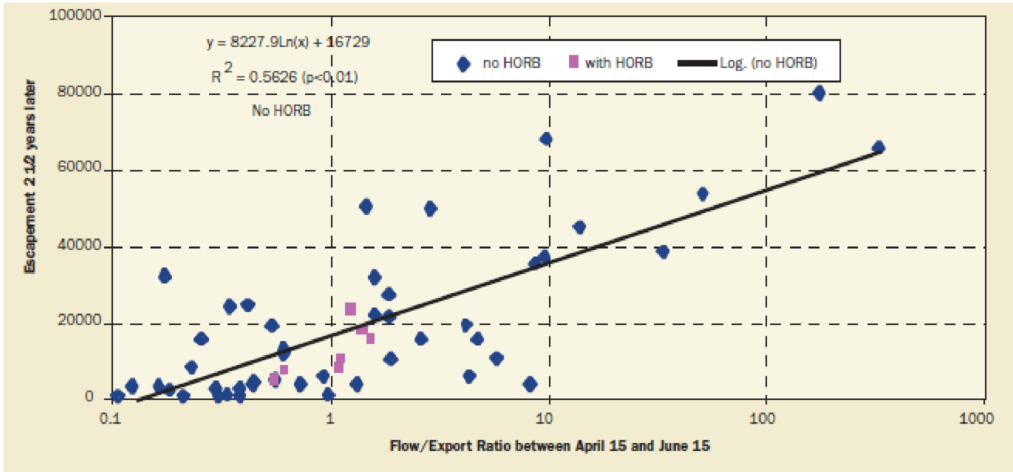

Figure 8-8. Relationship between adult Chinook salmon escapement and average Vernalis flow/Export ratio 2-1/2 years earlier (Source: SJRGA 2006).

- Acoustic monitoring studies from the modified, post 2006 VAMP experiments were unable to provide survival estimates at Antioch or Chipps Island, or in the ocean, comparable to those developed as part of the VAMP experiments conducted from 2000 to 2006 using the CWT. Thus, the acoustic tag data currently available cannot be used to assess, in the longer term, the role of San Joaquin River flow and SWP/CVP exports on juvenile salmon survival.

Overall, the VAMP survival studies showed a strong negative trend in juvenile fall-run salmon survival as a function of time (year), which was independent of the rates of flow and exports (Figure 8-9). The negative trend in survival was observed in absolute survival estimates using CWT salmon recaptured in sampling for juveniles at Chipps Island, as well as in sampling of adults from the ocean fishery. The negative trend was apparent for salmon released at Durham Ferry, Mossdale, and Dos Reis (Figure 8-10). Although the biological mechanisms and factors that resulted in the negative survival trend have not been determined, there is no evidence that the trend was the result of variation in Vernalis flow or SWP/CVP exports during the mid-April to mid-May period of these tests. It has been hypothesized that an increase in the abundance of predatory fish, such as largemouth bass, in the south and central Delta over the past decade may have been a major factor contributing to the declining trend in survival. Results of acoustic tagging studies conducted in the lower San Joaquin River and Delta in recent years provide additional support for the hypothesis that predation mortality for juvenile salmon is high.

8.1.2.2 Risk from Predation by Non-Native Fish Species

As discussed in Section 2, results of recent acoustic tag studies have shown evidence of high predation rates for juvenile salmon migrating through the lower San Joaquin River and Delta. Predation mortality by striped bass and largemouth bass has been identified as a major factor reducing the survival of juvenile salmon and steelhead entering Clifton Court Forebay (Gingras 1997, Clark *et al.* 2009), at fish salvage release sites (Miranda *et al.* 2010), and at other locations within the Central Valley rivers and Delta such as the Head of Old River (Bowen *et al.* 2009, Bowen and Bark 2010). Given the complex habitat conditions in the Delta that provide cover for predatory fish and the hydrologic conditions in the Delta dominated by tidal flows rather than Delta inflows, increased or minimum Delta inflows or outflows are unlikely to have any effect on the abundance or distribution of either largemouth bass or sunfish in the Delta. Increased Delta inflow would not be expected to change the seasonal temperature conditions in the Delta or other elements of largemouth bass and sunfish habitat.

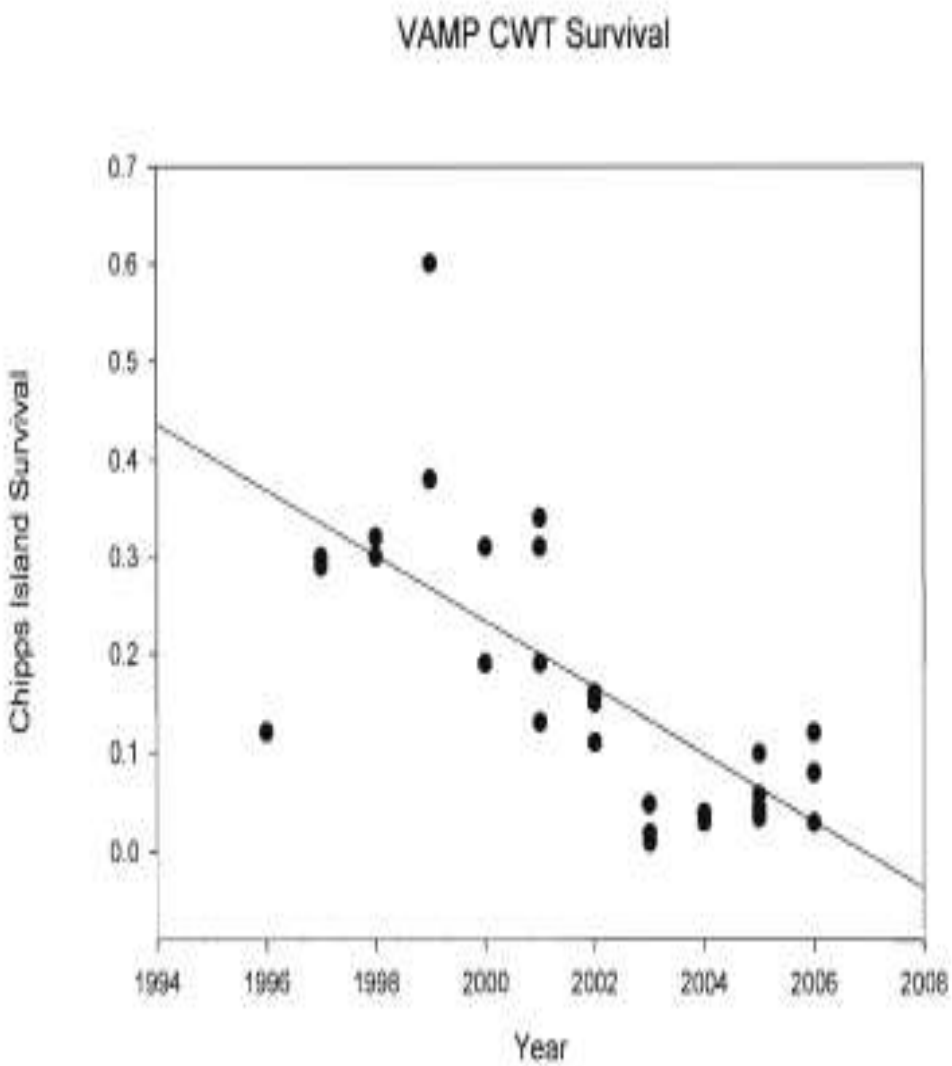

Figure 8-9. Trend in juvenile fall-run Chinook salmon survival in the lower San Joaquin River and Delta measured during VAMP studies (Source: SJRGA 2006).

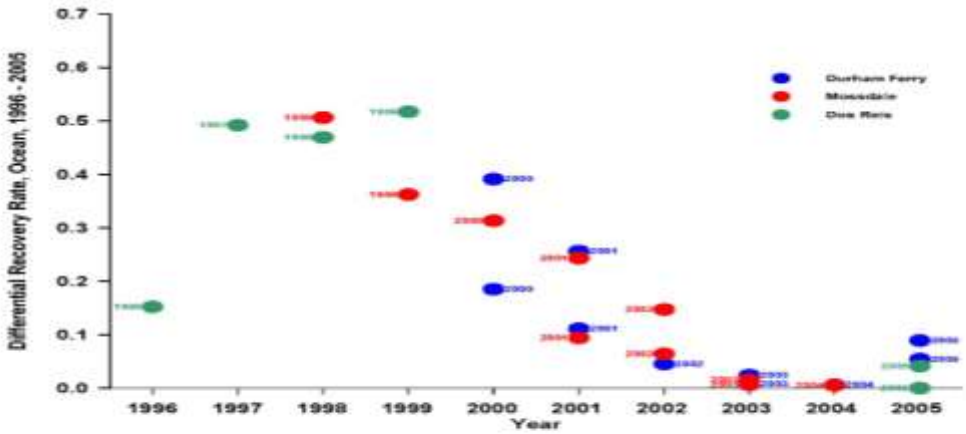

Exhibit 2. Declining trend over time in differential survival of Chinook salmon emigrating from the lower San Joaquin River as reflected in recaptures in the ocean fishery (Source: S. Greene, DWR, pers com.).

Figure 8-10. Juvenile salmon survival over time as a function of release site in the lower San Joaquin River (Source: S. Greene, pers. com.)

9 Delta

9.1 Background on Salmonid Use of Delta

The Delta serves as a migratory pathway for upstream immigrating adult and downstream emigrating juvenile salmonids. The Delta provides a transition area from upstream freshwater habitats in the rivers that serve as spawning and juvenile rearing habitat to coastal marine waters where salmonids rear and grow for a substantial proportion of their lifecycles. As discussed in Section 2, the Delta has been extensively modified, resulting in diminished habitat quality and availability for salmonids, and the species composition and trophic dynamics of the Delta have changed in response to the introduction and population expansion of non-native fish, macroinvertebrates, and aquatic plants.

SWP and CVP export operations, as well as the large number of individual in-Delta diversions, are several of the other factors that affect the Delta's dynamic conditions. Depending on Delta inflows and export rates and other Delta diversions, the direction and magnitude of flows in interior Delta channels can be altered and "reverse flows" can occur in Old and Middle rivers. These and other stressors (Section 2) can affect habitat quality and availability within the Delta, the migration pathways and behavioral response of juvenile salmon during migration through the Delta, as well as the species' health, growth, and survival.

Notwithstanding the effect of diversions on flows in Delta channels, the dominant factor affecting hydrodynamic conditions in the Delta is tidal action. The flow in Delta channels, as well as salinity intrusion into Suisun Bay and the Delta, is complex and driven to a large extent by tidal stage. The direction of flow in many areas of the Delta is determined by ebb and flood tidal conditions. Adding Delta inflows has very little impact on tidal action.

9.2 New Studies and Technologies

Much of the early research on juvenile salmonid migration and survival relied on CWT mark-recapture studies. In more recent years, innovations in acoustic tag technology have contributed to applying remote sensing to assess juvenile salmonid migration rates and pathways, predation, survival rates, and how various management actions (e.g., VAMP, 2012 Stipulation Study, etc.) affect the behavior and survival of juvenile salmon and steelhead during their migration through the Delta. There have also been a number of recent advances in other analytic tools and statistical analyses useful for application to salmonid issues, such as DSM2, and the Delta Passage Model.

Comprehensive analysis of data collected regarding juvenile salmonid migration, tidal hydrodynamics, water quality, fish surveys and the effects of flows and exports using these new technologies have contributed to an improved understanding of the Delta and its function as a salmonid migration pathway and as juvenile rearing habitat. Current information and technologies have also been extensively used in developing large-scale management programs, such as CVPIA and BDCP.

9.2.1 Acoustic Tagging Studies

Significant advances in recent years in the application of acoustic tag technology offer the opportunity to develop detailed information on the movement patterns and survival of individual salmon and steelhead as they migrate through Delta channels. Combining data regarding fish movement from the acoustic tag studies with data on water velocities, water quality, and other environmental conditions has substantially expanded the technical foundation for examining the response of juvenile salmonids to various management actions and environmental conditions.

9.2.1.1 Sacramento River Acoustic Tag Studies

Perry (2010) and Perry *et al.* (2010) used acoustically tagged late fall-run Chinook to track salmon behavior and route selection within the Delta. Figure 9-1 illustrates the acoustic tag detector array used by Perry to determine salmon migration pathways and movement rates as well as to develop estimates of reach-specific survival rates. Using results of these acoustic tag experiments, Perry was able to determine the probability that a juvenile salmon will select a given migration route at flow splits as a function of the fraction of Sacramento River flow entering each pathway (Figure 9-2). In the past, a basic assumption had been made that juvenile salmon and steelhead migrating through the Delta selected their routes as a direct proportion of the flow entering the route (e.g., fish follow in direct proportion to the flow). Perry's study provides empirical information on the behavior of juvenile salmon encountering a flow split. That information has now been integrated into new analytical tools, such as the DPM, used for simulating salmon migration and survival.

Results of the acoustic tag survival studies conducted by Perry also provide detailed information on reach-specific survival rates. These results (Figure 9-3) show that juvenile salmon migrating downstream in the mainstem Sacramento River or through Steamboat and Sutter sloughs typically had higher survival when compared to those fish that migrated into the interior Delta through the Delta Cross Channel or Georgiana Slough. These recent acoustic tracking study data are similar to the results from earlier CWT experiments, but provide an additional level of fine-grained, reach-specific information that is difficult to obtain using CWT tests. That said, the results of the Perry (2010) acoustic tagging studies include a limited number of tests over a 3-year period (2007, 2008, and 2009) and, therefore, reflect a relatively narrow range of environmental conditions. The acoustic tag studies done by Michel (2010) were also conducted over a 3-year period. Both the Perry (2010) and Michel (2010) studies were conducted using relatively large yearling late fall-run Chinook salmon and may not be representative of migration behavior or survival of other runs of Chinook salmon and steelhead. NMFS, USBR, DWR, and others are developing and conducting additional acoustic tag studies beginning in 2013 to address some of these shortcomings over the next 5 years.

DWR has applied high-resolution three-dimensional acoustic tagging technology to assess juvenile salmon movement and response to the non-physical barrier at Georgiana Slough (Section 7). The three-dimensional acoustic tag tracking system has the advantage of providing very high resolution data on the position of each fish within the water column and how each fish is responding to localized changes in channel configuration and water velocity fields. The technology can also evaluate factors such as localized predation mortality (Bowen *et al.* 2008, 2009, 2010) and the efficacy of potential management actions designed to benefit salmonids, such as the use of a non-physical barrier to guide the migration pathways of juvenile salmonids. Application of the three-dimensional tracking technology is best suited for relatively small areas where detailed high resolution information is needed. For the majority of Delta studies on salmonid migration route selection and survival, simpler one-dimensional acoustic detection is typically used and is still appropriate (Perry 2010, Michel 2010).

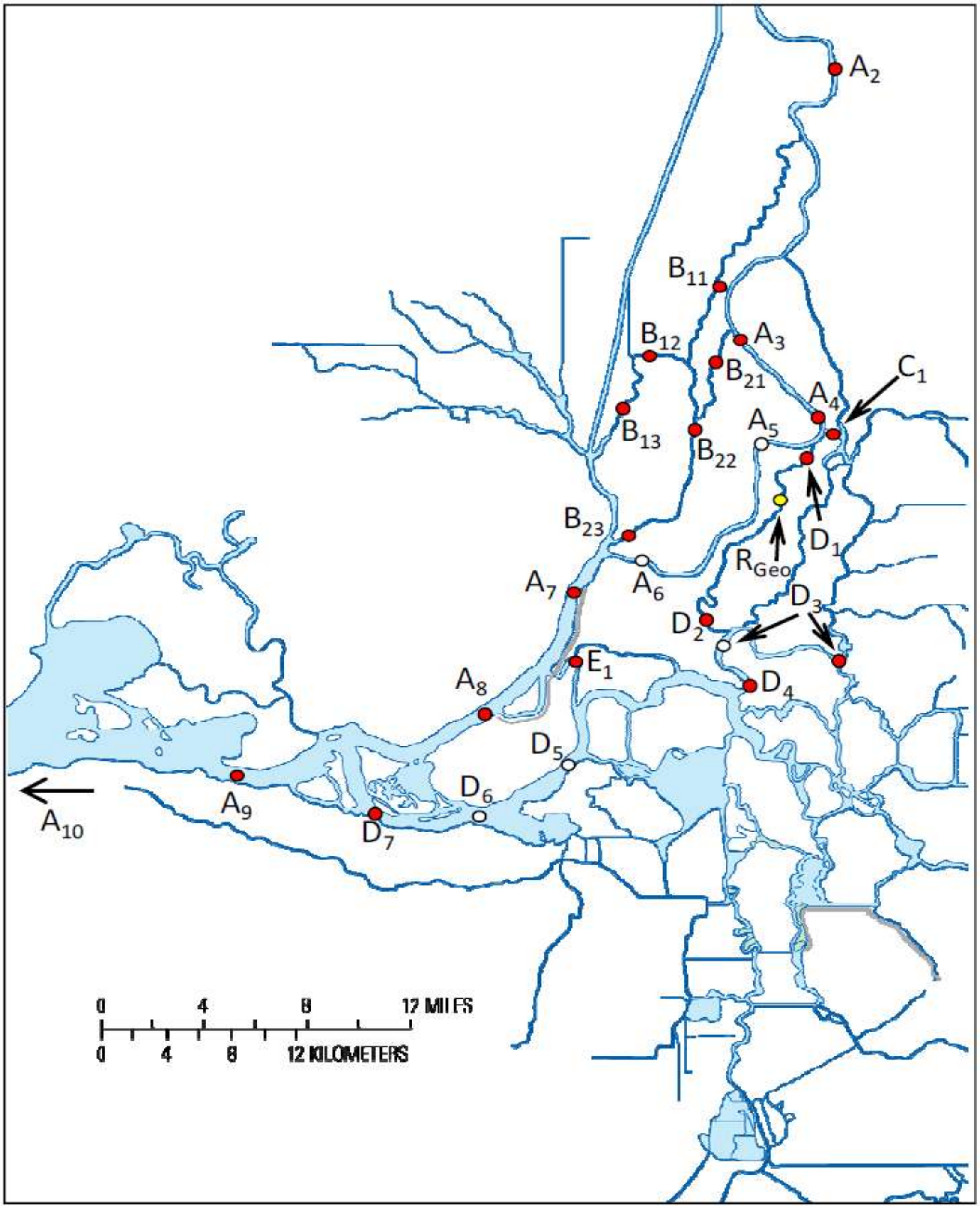

Figure 9-1. Acoustic receiver sites monitored in the north Delta and Sacramento River during acoustic tag studies using late fall-run Chinook salmon during the winter of 2009 (Source: Perry 2010). Open circles denote telemetry stations used in 2008 but not in 2009. The Sacramento release site was 19 river kilometers upstream of Site A_2. The Georgiana Slough release site is shown as the yellow circle labeled R_{Geo}.

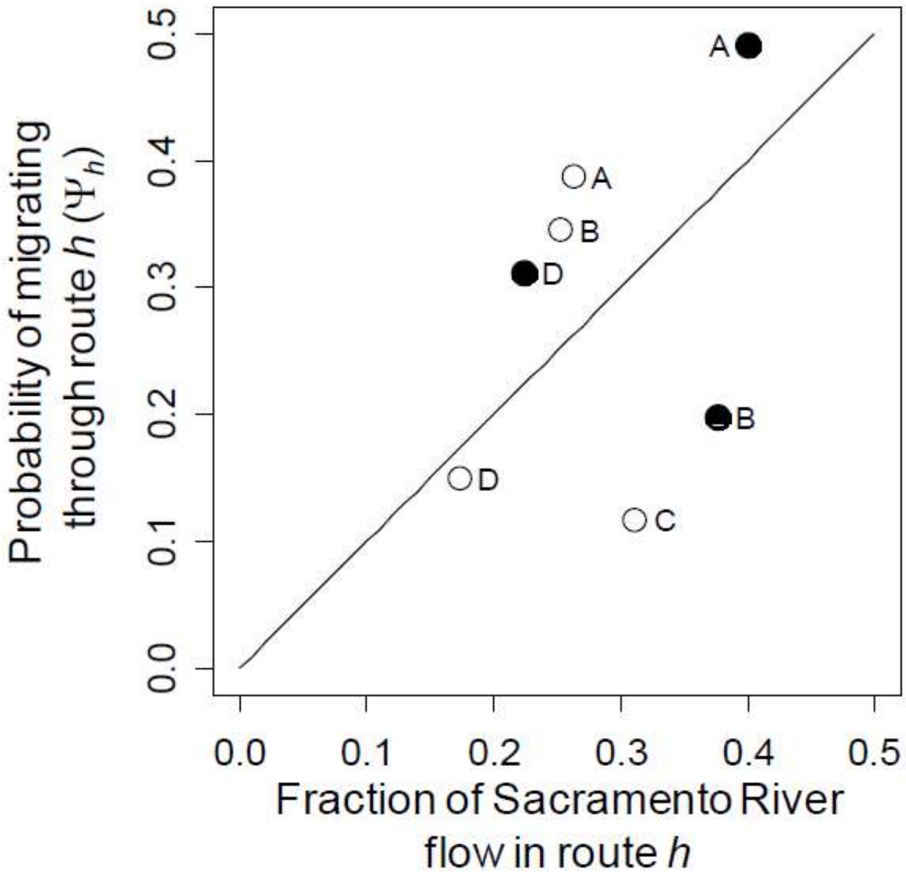

Figure 9-2. **Relationship between the fraction of Sacramento River water flowing into various north Delta channels and the probability of acoustically tagged juvenile late fall-run Chinook salmon migrating through the route (Source: Perry 2010). The open circles represent releases in December 2007 and the filled circles reflect releases in January 2008. Data labels A-D represent the Sacramento River, Steamboat and Sutter sloughs, the Delta Cross Channel, and Georgiana Slough, respectively.**

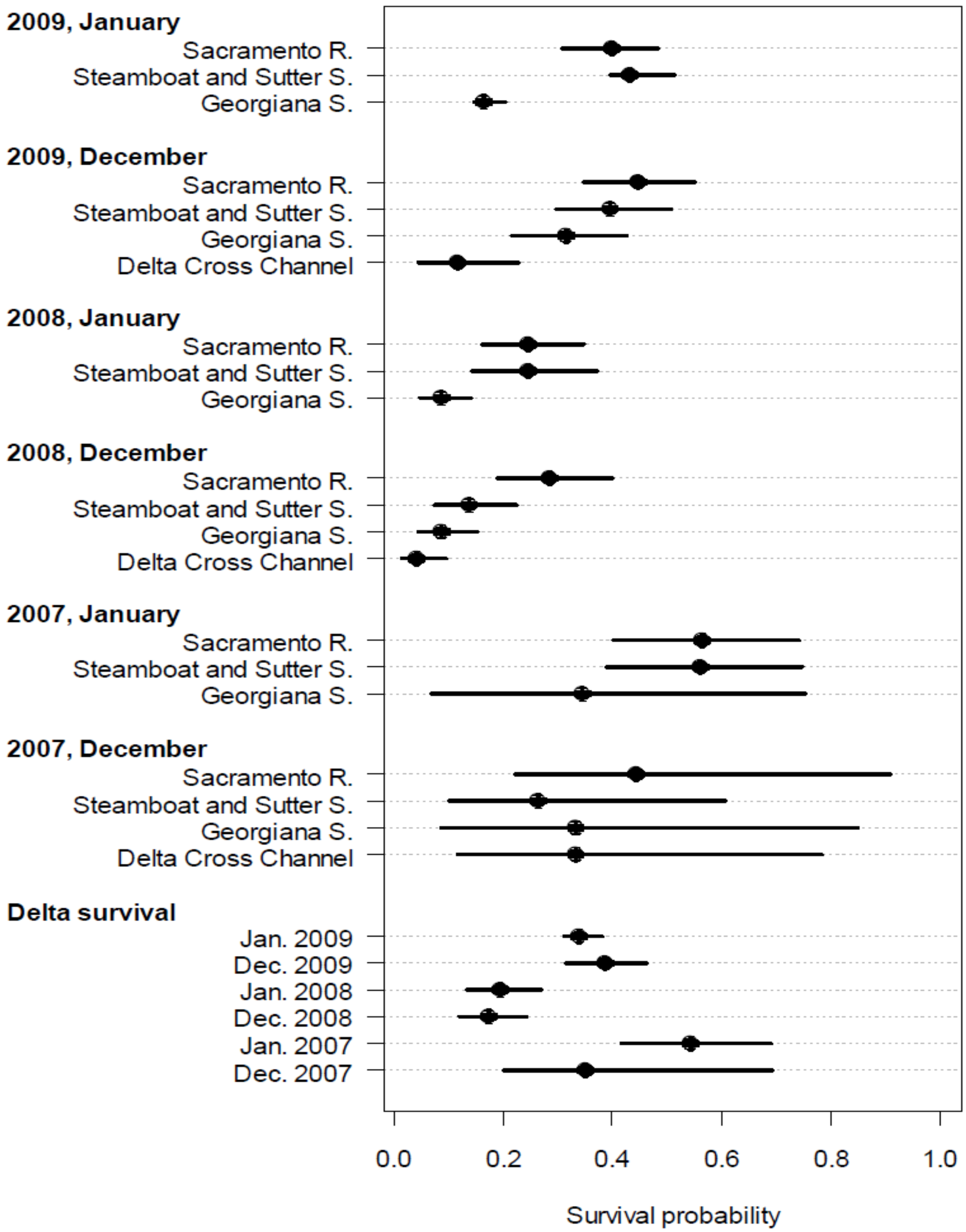

Figure 9-3. Route-specific survival estimates for migration of acoustically tagged juvenile late fall-run Chinook salmon in north Delta channels in 2007-2009 (source: Perry 2010).

9.2.1.2 San Joaquin River Acoustic Tag Studies

During the spring of 2012, two extensive acoustic monitoring programs were conducted to determine juvenile steelhead migration pathways and survival in the Delta based on juvenile steelhead releases into the lower San Joaquin River: (1) the Six-Year Steelhead Survival Study managed by Reclamation and required by the 2009 NMFS OCAP Biological Opinion; and (2) the 2012 Stipulation Study designed collaboratively by NMFS, DWR, and water users to provide data on the response of juvenile steelhead to hydrodynamic conditions in the central Delta as a function of various levels of OMR reverse flows.

The Six-Year Study released steelhead into the lower San Joaquin River at Durham Ferry. Stipulation Study steelhead were released farther downstream in the vicinity of Stockton, upstream of Turner Cut. For the Six-Year study, a network of acoustic tag detectors was deployed in the lower San Joaquin River and Delta, augmented by additional tag detectors through central and south Delta channels (Figure 9-4) designed to assess steelhead movement.

Data collected by the Stipulation Study tag detectors were downloaded daily or weekly, depending on site. Preliminary data on tag presence at each location was made available throughout the study period for use in managing south Delta export operations and OMR reverse flow levels. Detailed data analyses for both studies are currently underway.

A preliminary analysis examining the change in steelhead migration in response to OMR reverse flows has been undertaken. Project managers evaluated the hypothesis that steelhead would preferentially migrate downstream in the mainstem San Joaquin River when OMR levels were low (lower level of reverse flow), but would migrate more frequently into the central and south Delta—as reflected by the occurrence of acoustically tagged steelhead detected in Old and Middle rivers—when OMR reverse flows were greater (more negative).

The preliminary analysis used acoustic tag detections for steelhead released as part of the Six-Year study. Those fish were greater in number than those used in the Stipulation Study and were released further upstream of the Delta, thus giving the fish more time to acclimate to Delta conditions before encountering Delta channels leading to the south Delta, and were part of a larger sample size than the Stipulation Study. The number of fish entering the study area was represented by the quantity of acoustically tagged steelhead detected in the lower San Joaquin River at Site 9 (Figure 9-4). The number and percentage of tagged steelhead subsequently detected in Middle River at Site 2 and in Old River at Site 3 were used as an indicator of fish moving from the San Joaquin River into the central and south Delta. The number and percentage of tagged steelhead detected downstream at Site 11 (Prisoners Point) were used as an indicator that steelhead had successfully migrated downstream in the mainstem San Joaquin River. The preliminary analysis did not attempt to correct for variation in tag detection, calculate reach-specific survival or migration rates, or account for fish that may have been preyed. These issues will be addressed in detail in the complete data analysis.

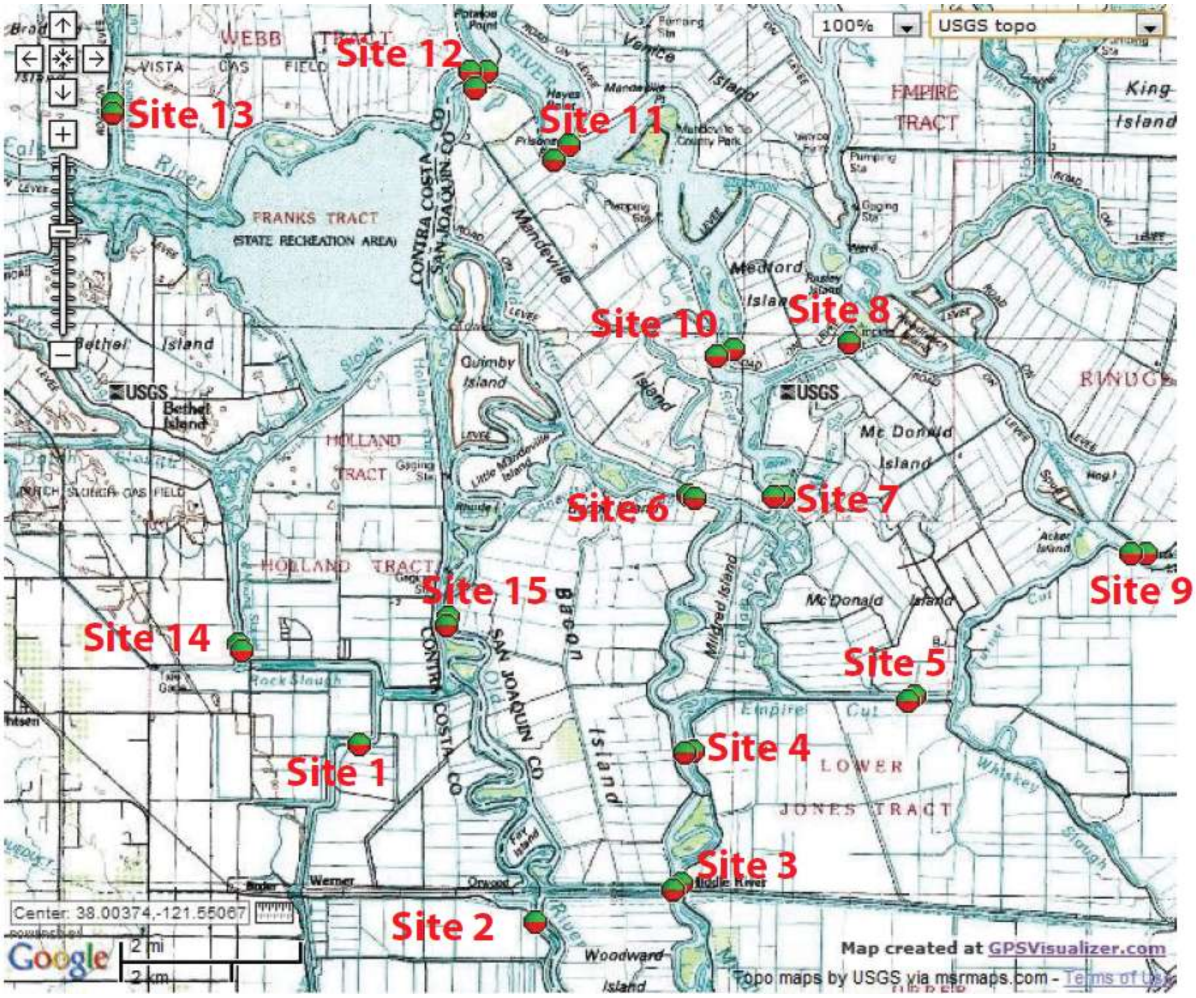

Figure 9-4. Map of the central and south Delta showing acoustic tag monitoring locations deployed as part of the 2012 Stipulation Study of juvenile steelhead migration through the Delta in response to OMR flows.

Table 9-1 summarizes the results of the preliminary acoustic tag analysis from the 2012 San Joaquin River steelhead study. The data were grouped under three separate export conditions: steelhead detected at Site 9 (the control site for this analysis) when OMR on the subject day was (1) less than -2,000 cfs, (2) between -2,000 and -4,000 cfs, and (3) greater than -4,000 cfs. Of the 395 steelhead deemed to have entered the Delta at Site 9, 24 were subsequently detected at Site 2 in the south Delta, 39 at Site 3 (also in the south Delta), and 120 downstream in the San Joaquin River and Prisoners Point (Site 11). The percentage of steelhead detected in the south Delta was 6 percent at Site 2 and 8 percent at Site 3 when OMR was less than -2,000. These results were similar to the results when OMR flows ranged between -2,000 and -4,000 cfs (4 percent detected at Site 2 and 8 percent at Site 3). The percentage of steelhead detected in the south Delta grew when OMR was greater than -4,000 (10 percent at Site 2 and 18 percent at Site 3); however, the sample size was substantially lower when OMR was greater than -4,000 cfs when compared to the other two conditions (Table 9-1).

The percentage of steelhead detected downstream at Prisoners Point was similar when OMR flows were less than -2,000 cfs (34 percent) and greater than -4,000 cfs (39 percent). This suggests that OMR did not have a substantial effect on the success of steelhead migrating downstream through the San Joaquin

River. When OMR flows ranged between -2,000 to -4,000 cfs (22 percent), the percentage of steelhead detected downstream was lower than expected.

These preliminary results require additional review and detailed analysis. At a minimum, they demonstrate that acoustic tag technology can be utilized to test alternative management proposals and the actual response of the target species. The technology also offers opportunities to use near real-time (daily) data to assist in management decision making and to develop empirical field data for target species usable to refine and validate predictions of simulation models and other analytical tools.

Table 9-1. Preliminary analysis of juvenile steelhead movement in the central and south Delta during spring 2012 in relation to OMR reverse flows.

	OMR Less than -2000 cfs	OMR Between -2000 & -4000 cfs	OMR Greater than -4000 cfs	Total	Percentage when OMR was Less than -2000 cfs	Percentage when OMR was -2000 to -4000 cfs	Percentage when OMR was Greater than -4000 cfs
Number of fish through Site 9 with:	169	149	77	**395**			
Number of fish from Site 9 to Site 2 with:	10	6	8	**24**	6	4	10
Number of fish from Site 9 to Site 3 with:	13	12	14	**39**	8	8	18
Number of fish from Site 9 to Site 11 with:	57	33	30	**120**	34	22	39

9.2.1.3 Lower Sacramento River/Delta Flow-Survival Relationship

The effect of Sacramento River flow on survival of juvenile fall-run Chinook salmon through the Delta has been assessed using results of USFWS CWT studies and flow data. Juvenile fall-run Chinook salmon were released into the lower Sacramento River in the vicinity of Sacramento (Verona to Clarksburg) and recaptured in USFWS trawling at Chipps Island to assess survival through the Delta (Brandes and McLain 2001). The analyses used DAYFLOW data regarding average flow at Freeport or Rio Vista over a 14-day period following each release. The duration of migration for each release group was calculated based on the time between release and the first fish recaptured at Chipps Island as well as the time to the last fish recaptured at Chipps Island. For many of the releases, multiple CWT codes were used. Results of the analysis were summarized separately by individual tag codes (typically, a release group of approximately 25,000 fish) and for the composite of multiple tag codes for those fish released at the same time and location (group survival).

Results of the analysis of survival as a function of Sacramento River flow at Freeport are shown in Figure 9-5. Survival as a function of flow at Rio Vista is shown in Figure 9-6. Results of these analyses show similar trends with high variability and low r^2 values (r^2=0.07 for flow at Freeport and r^2=0.03 for flow at Rio Vista), and relatively flat slopes to the regression lines, *suggesting that a relatively large change in* *flow would be required to achieve a relatively small change in survival (with high uncertainty).* These results are similar to results generated from CWT releases that occurred in the upper Sacramento River (Figures 7-10 and 7-11), suggesting that Sacramento River flow within the range evaluated has only a small effect on juvenile salmon survival for fish released into the upper watershed (upstream of Red Bluff Diversion Dam) and for those fish released downstream in the vicinity of Sacramento.

Results of salmon survival studies were plotted against time (independent of Sacramento River flows, exports, etc.) for both individual survival estimates (Figure 9-7) and for group survival estimates (Figure 9-8) based on tests conducted between 1996 and 2009. These results were also characterized by high variability; however, there was a general declining trend in survival as a function of time for both regressions. The declining survival over time observed in these data for the Sacramento River releases was similar, although not as pronounced, as the declining trend observed for fall-run Chinook salmon released on the San Joaquin River (Figure 8-9). *These results suggest that factors changing in the Delta that have affected juvenile salmon survival in recent years (e.g., increased predation mortality) are doing so independent of river flow and export operations.*

Additional analyses were performed to examine the relationship between Sacramento River flow and the rate of salmonid migration, as reflected by the number of days between the time of release and time of recapture. Results of the analysis of number of days to first recapture at Chipps Island as a function of flow are summarized in Figure 9-9 for flow at Freeport and Figure 9-10 for flow at Rio Vista. Results of the analysis of

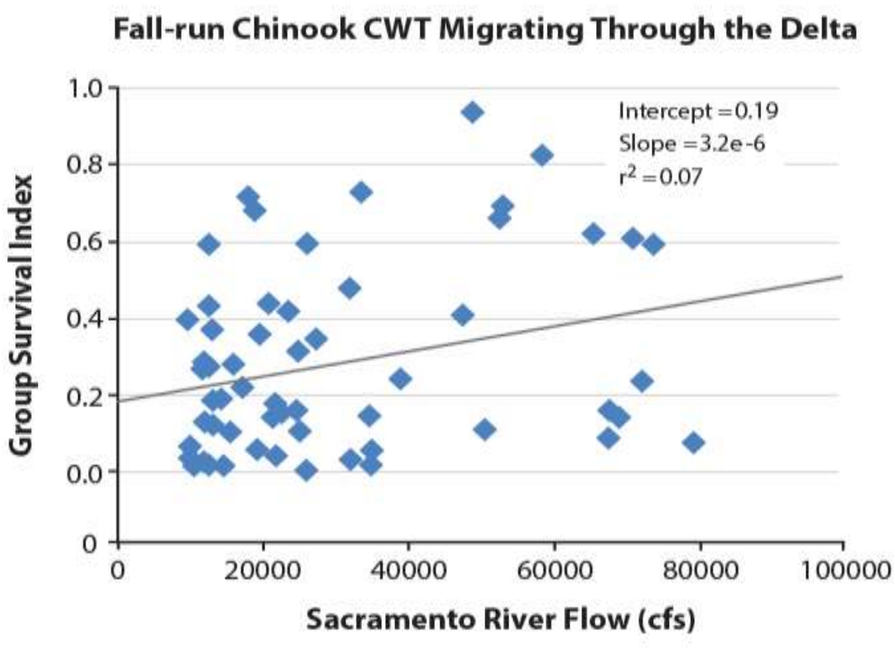

Figure 9-5. Relationship between average Sacramento River flow at Freeport over a 14-day period after release and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

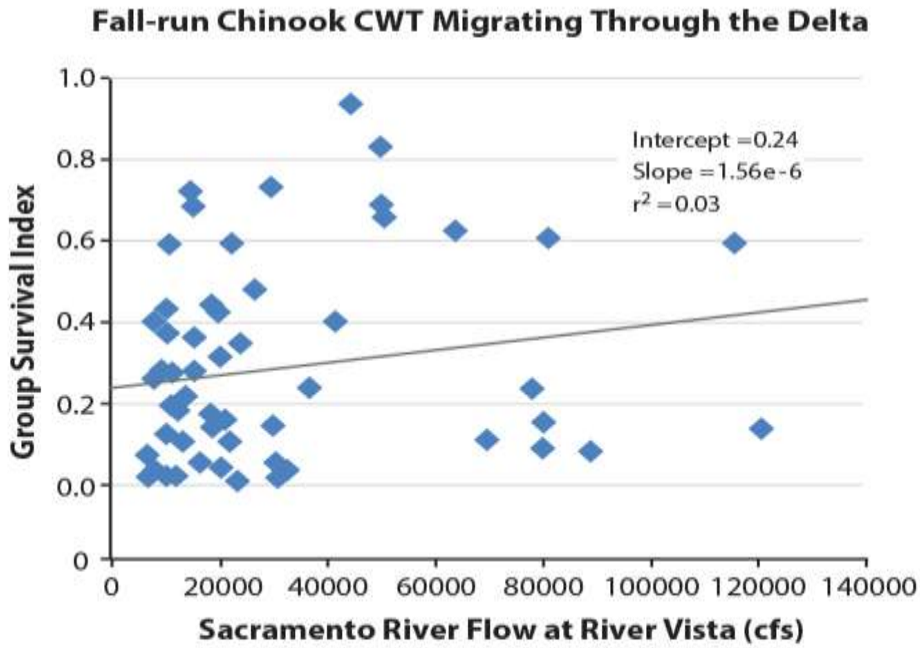

Figure 9-6. Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

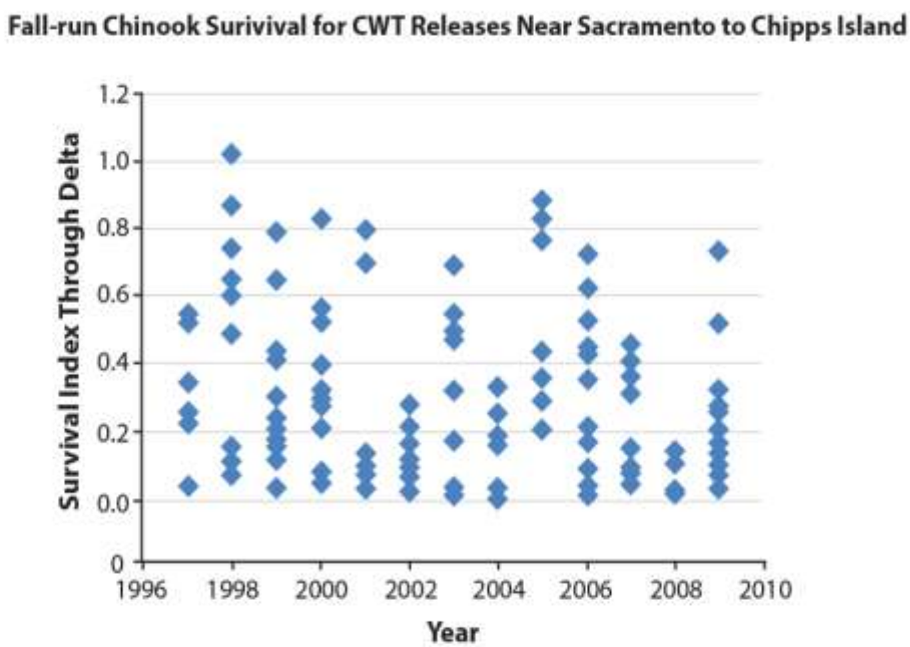

Figure 9-7. Relationship between year and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

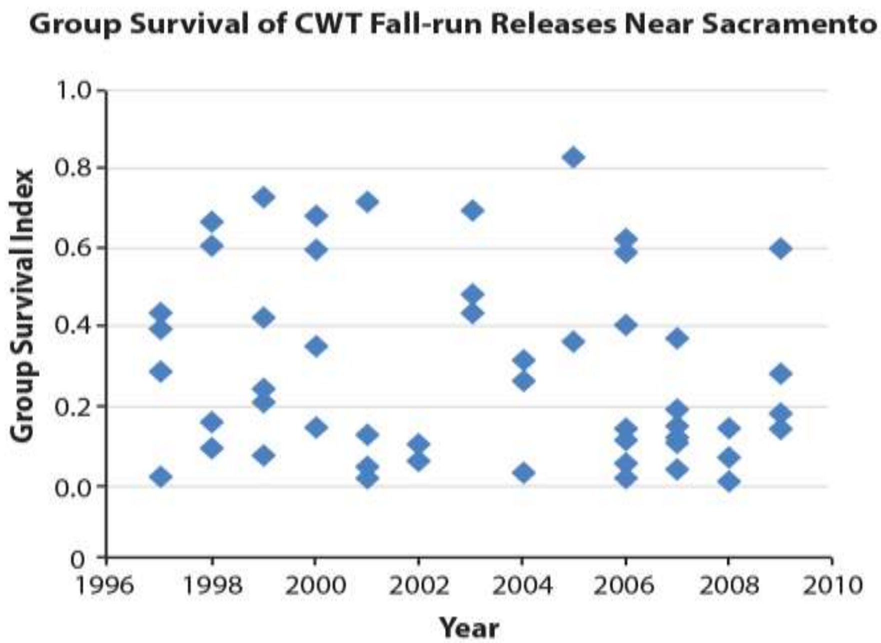

Figure 9-8. Relationship between year and juvenile fall-run salmon group survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

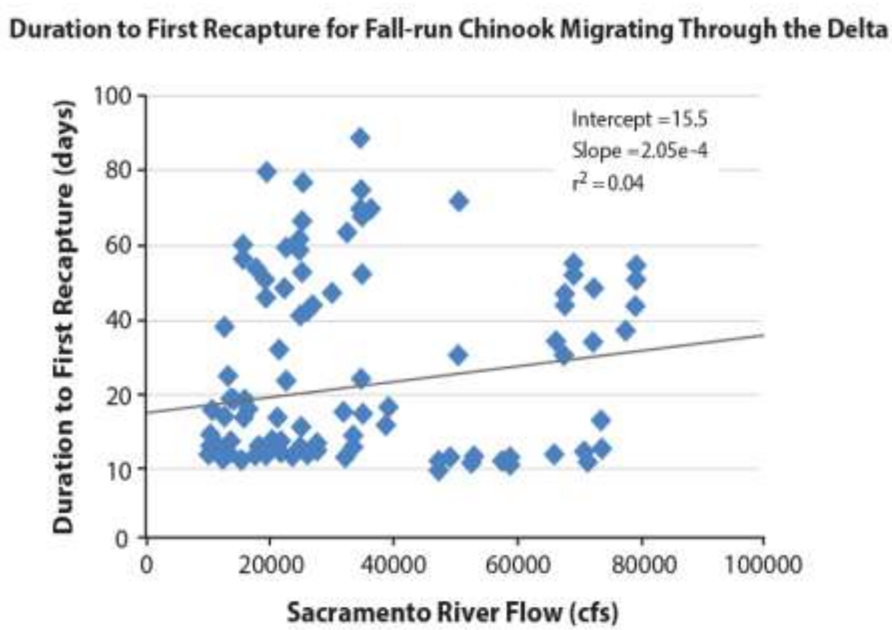

Figure 9-9. Relationship between average Sacramento River flow at Freeport over a 14-day period after release and the duration to first recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.

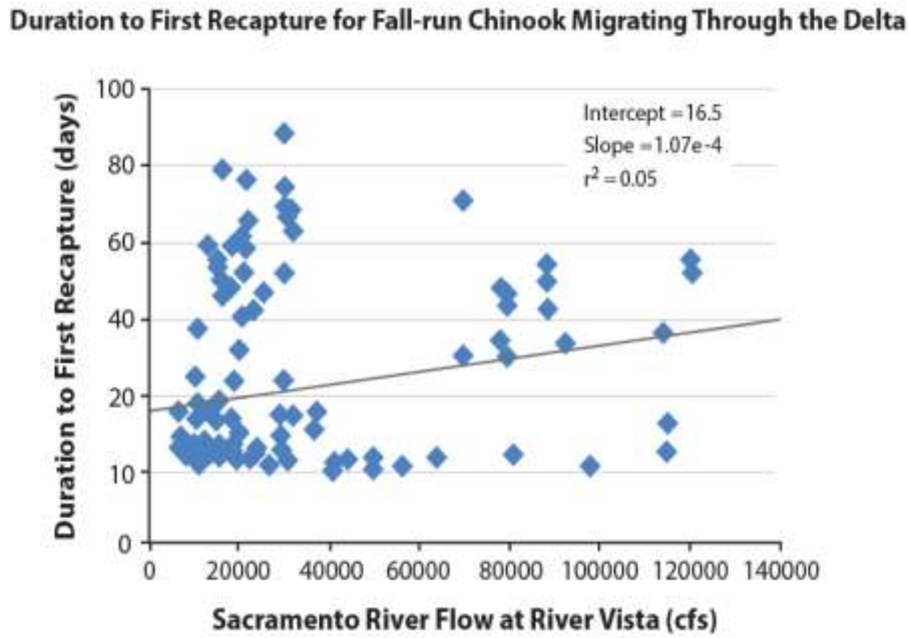

Figure 9-10. Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and the duration to first recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.

number of days to last recapture at Chipps Island as a function of flow are summarized in Figure 9-11 for flow at Freeport and Figure 9-12 for flow at Rio Vista. All of these relationships are characterized by high variability but, surprisingly, showed positive slopes. A positive slope to these regressions suggests a trend of increasing migration duration as river flow increased. *These results do not suggest that increasing river flow would be an effective strategy for reducing the duration of migration for juvenile Chinook in the lower Sacramento River.* Results of the ongoing acoustic tagging experiments will provide additional data that can be used to further evaluate the potential relationship between river flow and reach-specific migration rates.

The complexity of interacting variables affecting salmonid abundance year-to-year is reflected in two examples of Chinook salmon returns that have occurred in the last six years. For example, high river flows occurred in 2004 and 2005. Thus, it was expected that the abundance of fall-run Chinook salmon adults returning two to four years later would improve. In fact, the abundance of fall-run Chinook salmon adults returning to the Central Valley (and other rivers) in 2007(96,141 fall-run adults), 2008 (71,870 fall-run adults), and 2009 (53,129 fall-run adults) was extremely low, resulting in an emergency closure of the commercial and recreational fishery (Lindley *et al.* 2009).

Similarly, flows in the Sacramento River during the late winter and spring of 2006 were high throughout the juvenile salmonid migration period and were expected to improve survival and increase adult abundance. Average instream flows in the Sacramento River measured at Freeport during the 2006 migration period were 68,459 cfs in January, 50,211 cfs in February, 67,873 cfs in March, 74,842 cfs in April, and 52,835 cfs in May (Table 9-2). The flows during the 2006 migration season were substantially greater than in many other years. Despite these flow conditions, the escapement of adult fall-run Chinook salmon returning to the Central Valley two and one-half years later in 2008 and 2009 (71,870 and 53, 129 adults, respectively) represented the lowest level of abundance in the last 50 years (GranTab 2011).

By contrast, far lower Sacramento River flows at Freeport of approximately 9,000 to 21,000 cfs in the late winter and spring of 2009 is expected to produce a fall-run adult abundance in the ocean of 819,000 this year. (PFMC Feb. 12 Pre Season Report 1) Escapement estimates of fall-run Chinook salmon adults to the Central Valley are not yet available for 2012.

These examples illustrate the complexity of interacting factors that affect the population dynamics of Central Valley salmonids and the high degree of uncertainty that increasing reservoir releases or modifying export levels will result in a desired improvement in survival and abundance.

Table 9-2. Sacramento River average monthly flows (cfs) at Freeport and estimated adult fall-run Chinook salmon abundance.

	2006	2009
January	66,459 cfs	9,147 cfs
February	50,211 cfs	19,977 cfs
March	67,873 cfs	21,176 cfs
April	74,842 cfs	11,924 cfs
May	52,835 cfs	15,436 cfs
Estimated adult fall-run salmon abundance	53,129 2009	819,000 2012

2006 abundance is based on Central Valley escapement with no ocean or inland harvest; Source Chinookprod (2011)

2012 adult fall-run Chinook salmon abundance estimate (in the ocean and not escapement) is based on CDFG estimate of ocean stock; PFMC 2012

9.2.1.4 OMR Reverse Flow and Salmon Salvage

A substantial effort has been devoted to evaluating the potential relationship between OMR reverse flows and salvage of juvenile Chinook salmon at the SWP and CVP export facilities. Results of early analyses were criticized as being based on raw salvage (the expanded salvage estimate for a given period of time and species) as a function of OMR reverse flow. These early estimates did not adjust for the size of the fish population in a given year; applying such a raw salvage analysis, salvage may increase not as a function of OMR reverse flow, but rather as a function of increased abundance of juvenile salmon.

Revised analyses use normalized salvage (Deriso 2010), which is the expanded salvage estimate divided by the estimated abundance of that species passing through the Delta. Results of the normalized salvage as a function of OMR reverse flows are shown in Figure 9-13 for juvenile winter-run Chinook salmon (December-March) and Figure 9-14 for juvenile spring-run Chinook salmon (March-May). *Results of both of these analyses show no relationship between the magnitude of OMR reverse flow and normalized salvage over a range of OMR reverse flows exceeding -8,000 cfs* (Deriso 2010).

9.2.1.5 Export:Inflow Ratio and Salmon Salvage

The export:inflow ratio has been used as a method for managing south Delta export levels to protect sensitive fish from the risk of entrainment into the export facilities. D-1641 uses the E:I ratio to prescribe the percentage of water flowing into the Delta that can be exported during the later winter and spring (35 percent maximum exports) and during the summer, fall, and early winter (65 percent maximum exports).

Analyses have been performed to assess the relationship between the E:I ratio and juvenile salmon salvage (Deriso 2010). Results of the analysis for juvenile winter-run Chinook salmon are presented in Figure 9-15 for the seasonal period from December-March of 2000-2007. The analysis showed no relationship between the E:I ratio and the entrainment index for juvenile winter-run salmon but did show two unusually high data points. A second analysis was performed by Deriso (2010) using the same data for juvenile winter-run salmon which excluded the two outlier data points (Figure 9-16). That analysis showed a slight negative trend, with decreasing salvage as the E:I ratio increased. The two unusually high levels of salvage shown in Figure 9-15 appear to be outliers, however, complete results of the statistical analyses are shown with (Figure 9-15) and without (Figure 9-16) the two unusually high data points. Results of the statistical analyses were similar in showing very little relationship between the E:I ratio and salvage each with low r^2 values (r^2 = 0.004 from Figure 9-15 and r^2 = 0.0891 from Figure 9-16). A similar analysis was performed using data on juvenile spring-run Chinook salmon salvage during the months of March – May over the period from 2000 to 2007.

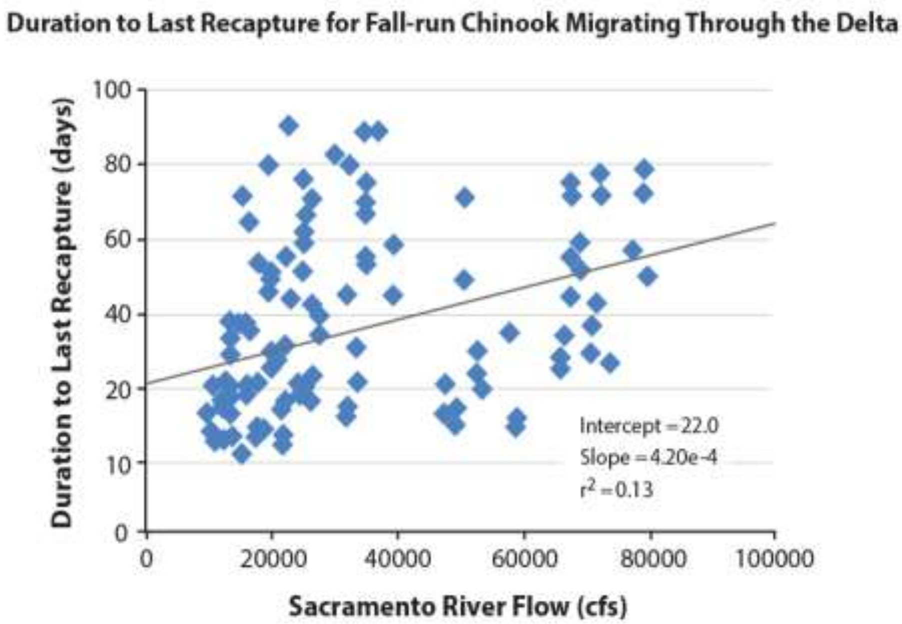

Figure 9-11. Relationship between average Sacramento River flow at Freeport over a 14-day period after release and the duration to last recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.

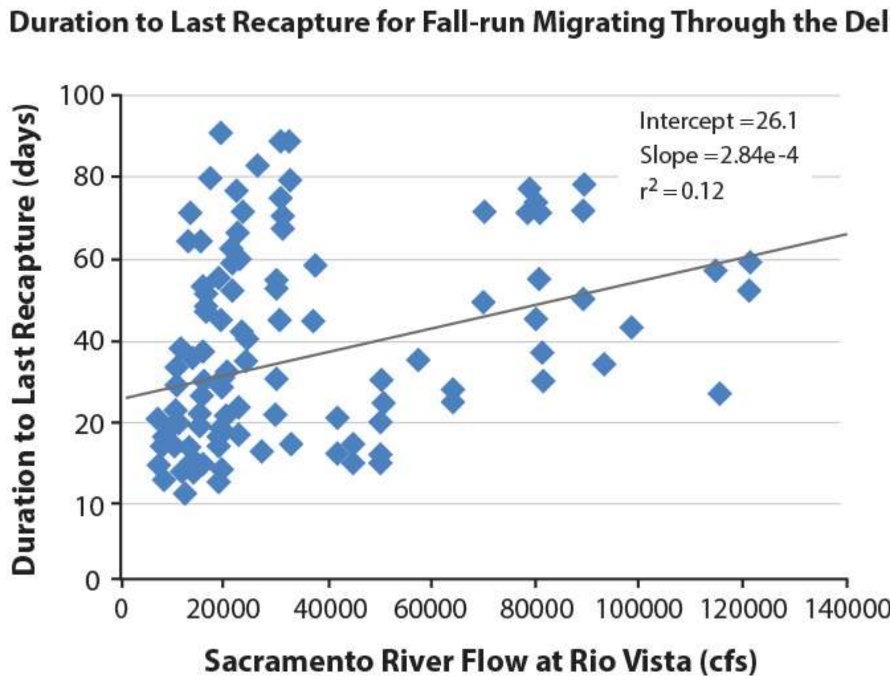

Figure 9-12. **Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and the duration to last recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.**

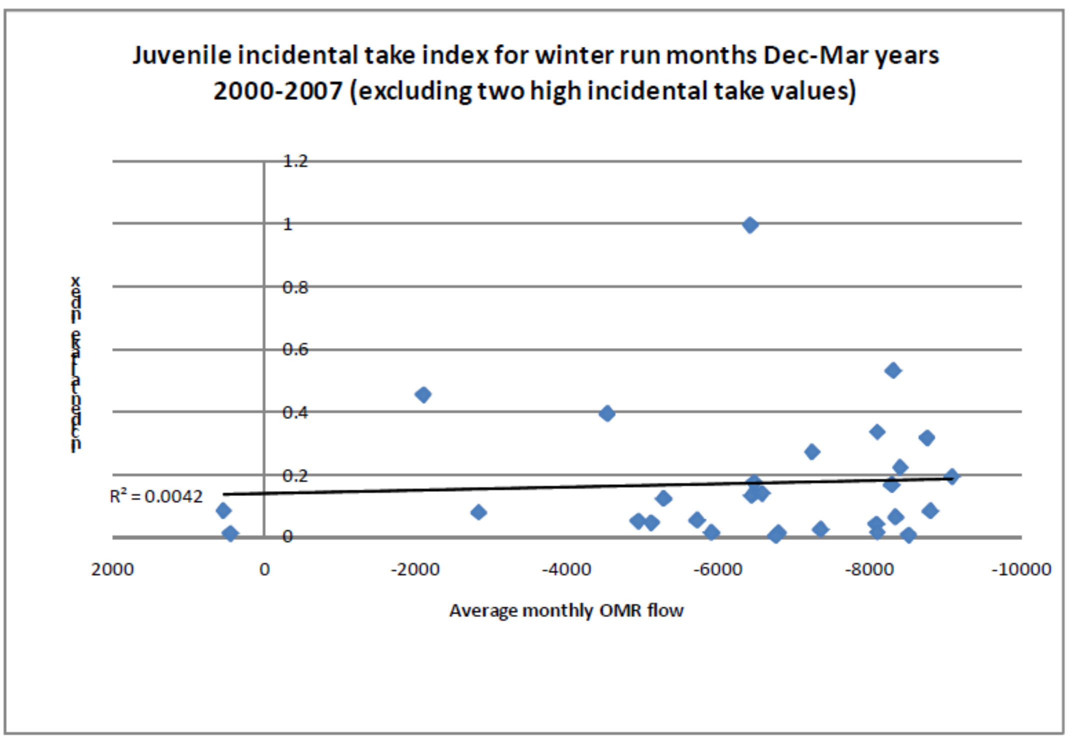

Figure 9-13. **Relationship between OMR for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007 excluding two unusually high observations of salvage (Source: Deriso 2010).**

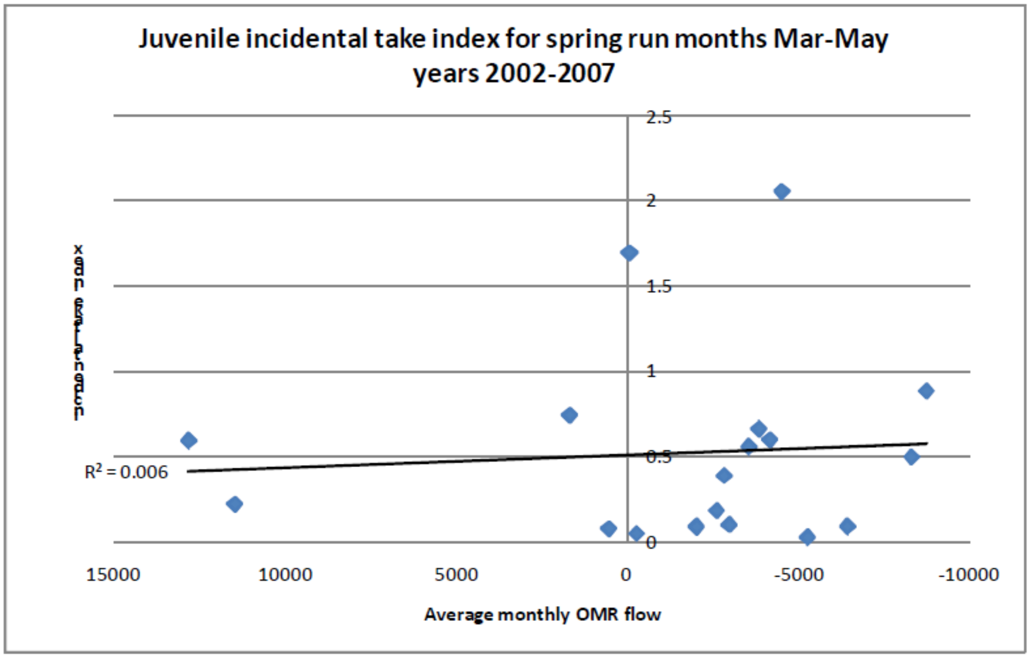

Figure 9-14. **Relationship between OMR for south Delta exports and salvage of juvenile spring-run Chinook salmon at the export facilities during March-May 2002-2007 (Source: Deriso 2010).**

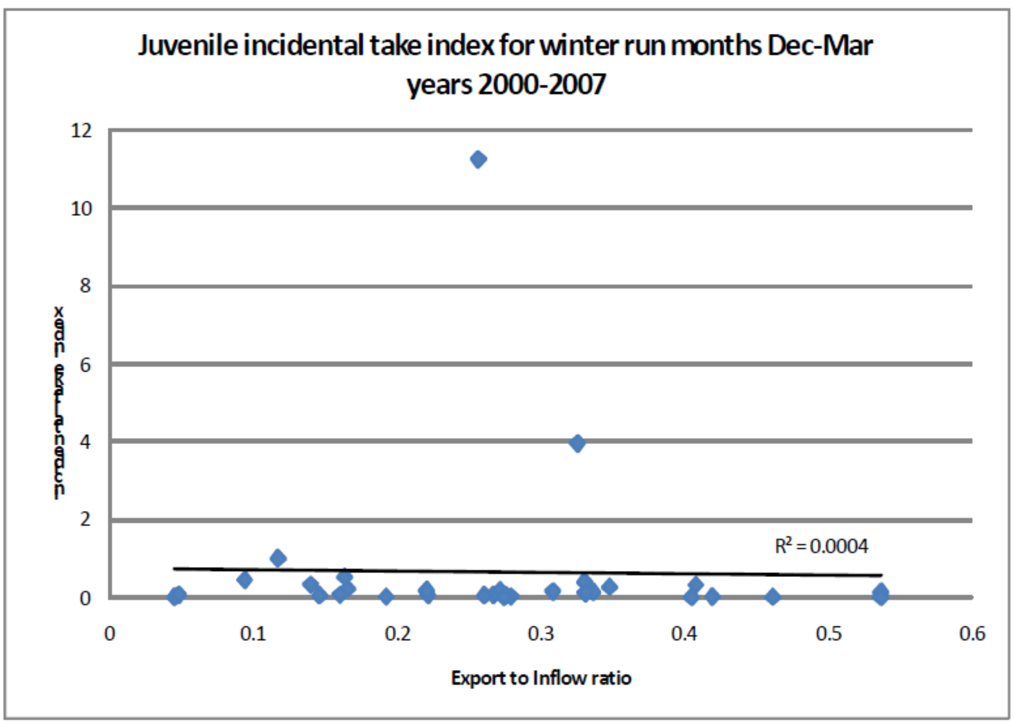

Figure 9-15. **Relationship between E:I ratio for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007, all data included (Source: Deriso 2010).**

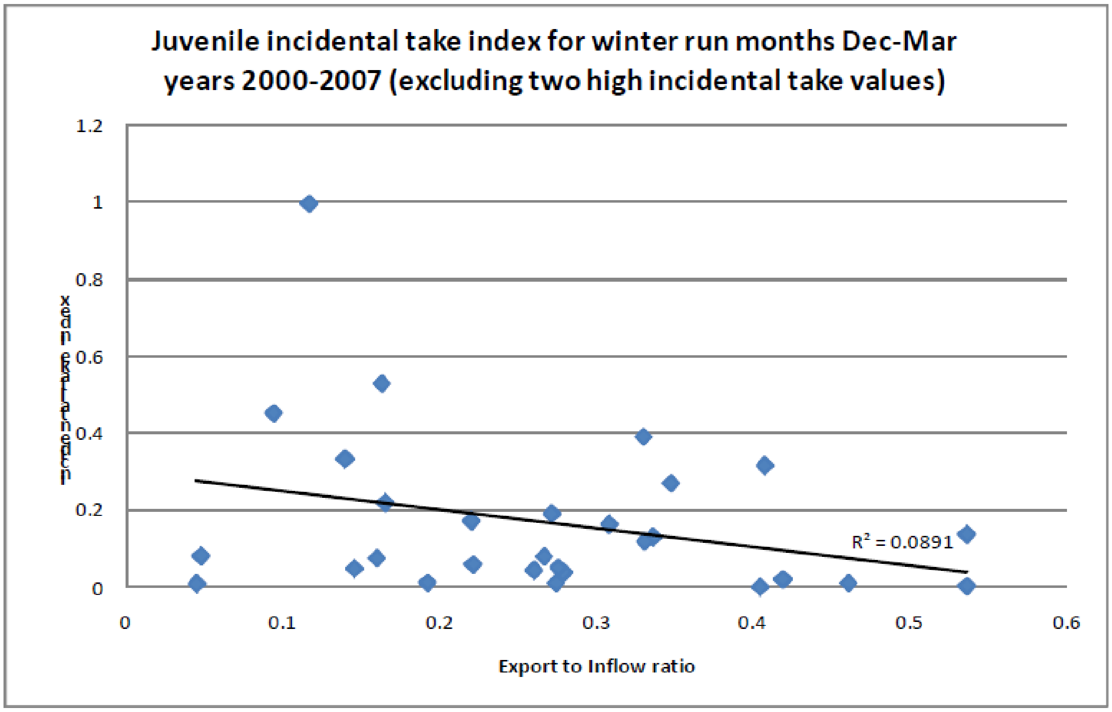

Figure 9-16. Relationship between E:I ratio for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007 excluding two unusually high observations of salvage (Source: Deriso 2010).

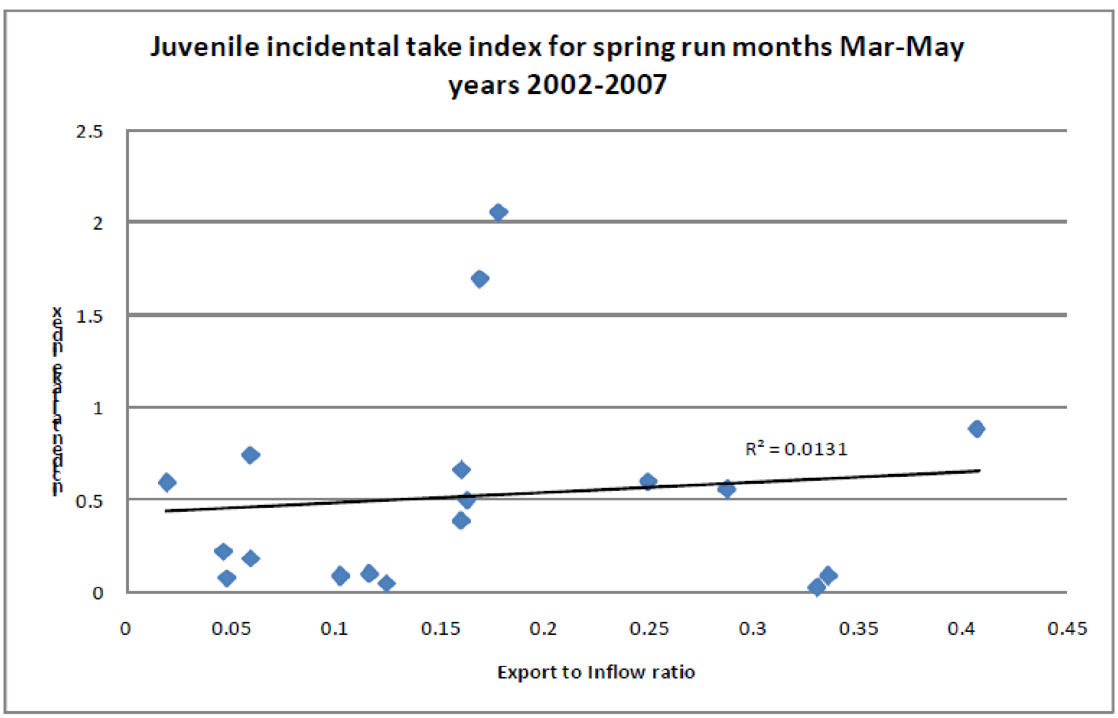

Figure 9-17. Relationship between E:I ratio for south Delta exports and salvage of juvenile spring-run Chinook salmon at the export facilities during March-May 2002-2007 (Source: Deriso 2010).

(Figure 9-17). These results showed a slight positive slope. For all three of these analyses, the r^2 values were very low (0.004 to 0.08), and the slopes were all close to zero, suggesting that there is little or no direct relationship between juvenile winter-run and spring-run Chinook salmon salvage and the E:I ratio during the seasonal period when these salmon juveniles are migrating through the Delta. Additional analysis of results of acoustic tagging studies conducted in the Delta will provide further information on the potential direct and indirect effects of south Delta export operations on the migration and risk of entrainment of juvenile salmon and steelhead in the future.

9.2.1.6 Predation on Juvenile Steelhead within Clifton Court Forebay

Results of mark-recapture studies conducted by releasing juvenile fall-run and late fall-run Chinook salmon into Clifton Court Forebay (Figure 9-18), and subsequently monitoring the number of tagged fish collected in SWP fish salvage operations, showed that salmon losses in the Forebay were high (Gingras 1997). Juvenile salmon used in these tests ranged in length from 44 to 112 mm. Estimates of pre-screen losses of these juvenile salmon in the Forebay in 8 studies conducted between 1976 and 1993 ranged from 63.3 to 99.2 percent, with an overall average of 86.5 percent. Predation within the Forebay by species such as striped bass was identified as the cause of the high mortality. It was hypothesized that the high mortality rates applied to smaller juvenile Chinook salmon, but pre-screen losses for larger yearling steelhead were expected to be substantially lower.

To test the pre-screen loss of yearling steelhead in the Forebay, a series of experiments was developed and conducted in 2005, 2006, and 2007 (Clark *et al.* 2009). Juvenile steelhead were tagged with various methods, including PIT and acoustic tags, and released in small groups at the radial gate at the head of the Forebay when the gate was open. Striped bass were also captured with hook and line within the Forebay and their movements monitored using acoustic tags. Based on pre-screen loss estimates using PIT tags, the loss was 82 percent with 95 percent confidence intervals of 3 percent. Results of these tests confirmed that there are predation hot-spots within the Delta where predation mortality on juvenile salmon and steelhead can be very high.

Figure 9-18. Clifton Court Forebay.

9.2.1.7 SWP/CVP Salvage Rates for Salmonids

Survival estimates for spring-run salmon have been developed by USFWS based on results of CWT mark-recapture studies conducted on the mainstem Sacramento River using late fall-run Chinook salmon juveniles as a surrogate for spring-run. Late fall-run Chinook salmon have been used as surrogates because spring-run salmon are not available in large numbers from hatcheries on the Sacramento River for use in testing. In addition, juvenile production in the tributaries is difficult to quantify (e.g., no estimates comparable to the winter-run Juvenile Production Estimate (JPE) are available for juvenile spring-run salmon production). However, tagged juvenile salmon reared at the Coleman National Fish Hatchery have sometimes been released into Battle Creek between late-November and mid-January to simulate the downstream migration and survival of juvenile spring-run Chinook salmon.

The USFWS has released CWT late fall-run salmon for use as surrogates to estimate spring-run Chinook salmon expanded salvage (to account for the time when salvage is sub-sampled but have not been expanded to account for pre-screen losses) at the SWP and CVP export facilities as a percentage of the number of tagged fish released (Tables 9-3 and 9-4). Annual expanded salvage estimates of the percentage of tagged salmon that were subsequently salvaged range from 0 to 0.46 percent, and have averaged 0.12 percent. These spring-run salvage estimates are consistent with actual salvage of winter-run Chinook salmon as a function of the JPE (Table 9-5). Estimated spring-run and winter-run salvage by the Projects are thus both consistently low (less than 0.5 percent) under a variety of export rates OMR reverse flows, and river inflows into the Delta. While the estimates of salvage have been variable, they do not show a trend of either increasing or decreasing salvage as a percentage of the number of CWT surrogate salmon released.

Table 9-3. Summary of survival estimates and expanded salvage for CWT juvenile late fall-run Chinook salmon (spring-run surrogates) from release to Chipps Island. Cohorts contributing to the 2007 escapement are highlighted in gray.

Water year	Release Groups	Number Released [1]	Number Recovered [2]	Survival Index	Expanded SWP/CVP Salvage	% Salvage
1994	3	186,876	66	43.6%	370	0.198%
1995	3	392,918	65	25.7%	423	0.108%
1996	3	360,346	83	38.5%	0	0.000%
1997	3	376,416	87	40.7%	386	0.103%
1998	2	265,217	80	38.5%	28	0.011%
1999	3	228,128	36	28.6%	202	0.089%
2000	3	177,902	17	16.3%	152	0.085%
2001	3	227,132	75	47.1%	443	0.195%
2002	3	261,716	84	53.1%	1,208	0.462%
2003	2	201,505	40	20.0%	466	0.231%
2004	3	226,788	32	18.8%	0	0.000%
2005	2	190,985	68	54.3%	171	0.090%
2006	2	258,999	42	20.1%	77	0.030%
2007	2	244,892	21	11.1%	162	0.066%
Average	**3**	**257,130**	**57**	**32.6%**	**302**	**0.119%**

[1] All CWT fish were reared in the Coleman Hatchery and were released into Battle Creek between late November and mid-January.
[2] CWT fish were recovered in the USFWS midwater trawl at Chipps Island.

Table 9-4 depicts the results of a similar CWT mark-recapture study in which late fall-run juvenile Chinook salmon (Coleman National Fish Hatchery origin) were released during February and March at the Red Bluff Diversion Dam on the upper Sacramento River (average juvenile lengths ranging from 38 to 58 mm representing young-of-the-year juveniles) and recovered at the SWP and CVP fish salvage facilities. Although a smaller number of tagged fish were released in the RBDD study, results showed expanded salvage estimates ranging from 0 to 0.036 percent. These CWT release experiments have typically salvaged a low percentage of released fish. *Overall, results for all the analyses performed using CWT salmon to assess SWP and CVP salvage (Table 9-6) show a consistent pattern of very low salvage*. These results are again consistent with the calculated low juvenile winter-run Chinook salmon salvage.

Table 9-4. Release and percent expanded salvage of coded-wire tagged Coleman National Fish Hatchery late-fall run Chinook released at Red Bluff Diversion Dam during February and March, for years 1995 and 1999-2006. Released Chinook are assumed to act as surrogates for emigrating juvenile spring-run Chinook salmon. Data from summary of CWT release and recoveries from CDFG's website: http://www.delta.dfg.ca.gov/jfmp/docs/1993%20%202006%20CI%20survival%20table%20Updated%20Jun.2007.pdf

Water Year	Released	Ave. Size (mm)	Expanded Salvage Recoveries			% Salvaged
			SWP	CVP	Total	
1995	92202	49	0	0	0	0.000
1999	38725	38	0	0	0	0.000
2000	96139	57	12	6	18	0.019
2001	91007	46	0	9	9	0.010
2002	49774	52	12	6	18	0.036
2003	100043	58	0	24	24	0.024
2004	98623	51	0	6	6	0.006
2005	47276	53	0	0	0	0.000
2006	49700	48	0	0	0	0.000

*Water years 2005 and 2006 correspond with spring-run brood years 2004 and 2005 which contributed to 2007 adult escapement.

Table 9-5. Winter-run Chinook salmon juvenile production estimates (JPE) entering the Delta, expanded loss of juvenile winter run (excluding clipped fish) at export pumps, and percentage of winter-run juveniles lost at the pumps. JPE estimates from Bruce Oppenheim, NMFS. Expanded loss data downloaded from CDFG at ftp://ftp.delta.dfg.ca.gov/salvage.

Water Year	JPE	Expanded Loss			% Juvenile Loss
		SWP	CVP	Combined	
1995	74,500	476	565	1,040	1.40
1996	338,107	4,650	2,637	7,287	2.16
1997	165,069	326	187	514	0.31
1998	138,316	1,178	632	1,810	1.31
1999	454,792	3,161	554	3,715	0.82
2000	289,724	4,705	562	5,267	1.82
2001	370,221	18,825	1,212	20,037	5.41
2002	481,555	2,776	537	3,313	0.69
2003	1,798,275	6,250	559	6,809	0.38
2004	2,089,491	6,984	712	7,696	0.37
2005	488,345	1,247	126	1,373	0.28
2006	1,277,486	2,279	322	2,601	0.20
2007	3,739,069	1,742	1,556	3,298	0.09%
2008	589,900			1,316	0.22%
2009	617,783			1,948	0.17%
2010	1,179,633			4,024	0.34%

*Water years 2005 and 2006 correspond with winter-run brood years 2004 and 2005 which contributed to 2007 adult escapement.

Table 9-6. Summary of coded wire tag mark-recapture studies, 1993-2009 (Source: USFWS unpublished data).

Percent of all Tagged Salmon Smolts Released from 1993-2009 that Suffered Direct Mortality at the Export Pumps												Total Fish Released	Total Fish Lost
River	Source of Fish	Species	Release Location	Number of Release Groups	Average Number of Fish Per Group	Percent Direct Mortality per Release Group							
						Banks Pumping Plant			Tracy Pumping Plan				
						Min	Ave	Max	Min	Ave	Max		
Sacramento River System	Coleman Hatchery	Late fall-run	Hatchery	58	218,305	0.00	0.40	2.99	0.00	0.04	0.30	12,661,690	55,711
			Delta[2]	28	111,754	0.00	0.72	6.43	0.00	0.06	0.37	3,129,112	24,407
		Fall-run	Hatchery	31	493,467	0.00	0.08	2.13	0.00	0.00	0.07	15,297,477	12,238
			Delta[2]	26	82,947	0.00	0.05	0.36	0.00	0.00	0.02	2,156,622	1,078
	Coleman/Livingston Stone Hatcheries[1]	Winter-run	Upper Sacramento River	18	108,919	0.00	0.05	0.28	0.00	0.01	0.03	1,960,542	1,176

Percent of all Tagged Salmon Smolts Released from 1993-2009 that Suffered Direct Mortality at the Export Pumps

River	Source of Fish	Species	Release Location	Number of Release Groups	Average Number of Fish Per Group	Banks Pumping Plant Min	Banks Pumping Plant Ave	Banks Pumping Plant Max	Tracy Pumping Plan Min	Tracy Pumping Plan Ave	Tracy Pumping Plan Max	Total Fish Released	Total Fish Lost
						Percent Direct Mortality per Release Group							
	Feather River Hatchery	Fall-run	Hatchery	13	114,296	0.00	0.00	0.01	0.00	0.00	0.00	1,485,848	0
	Feather River Hatchery	Fall-run	Delta[2]	89	113,920	0.00	0.03	0.41	0.00	0.00	0.02	10,138,880	3,042
	Feather River Hatchery	Fall-run	Delta[3]	21	94,442	0.00	0.36	1.43	0.00	0.51	1.44	1,983,282	17,255
	Feather River Hatchery	Spring-run	Hatchery	6	649,981	0.00	0.00	0.00	0.00	0.00	0.01	3,899,886	0
	Tagged Wild Fish	Spring-run	Butte Creek	11	121,726	0.00	0.01	0.04	0.00	0.00	0.00	1,338,986	134
	Mokelumne River Hatchery	Fall-run Yearlings	Hatchery	12	96,570	0.00	0.27	1.33	0.01	0.04	0.10	1,158,840	3,592
	Mokelumne River Hatchery	Fall-run	Hatchery	38	109,408	0.00	0.02	0.21	0.00	0.01	0.08	4,157,504	1,247

Percent of all Tagged Salmon Smolts Released from 1993-2009 that Suffered Direct Mortality at the Export Pumps												Total Fish Released	Total Fish Lost
River	Source of Fish	Species	Release Location	Number of Release Groups	Average Number of Fish Per Group	Percent Direct Mortality per Release Group							
						Banks Pumping Plant			Tracy Pumping Plan				
						Min	Ave	Max	Min	Ave	Max		
			Delta[2]	14	90,938	0.00	0.09	1.15	0.00	0.01	0.13	1,273,132	1,273
San Joaquin River System	Merced River Hatchery	Fall-run Yearlings	Hatchery	3	71,943	2.81	4.24	5.56	1.26	2.28	2.81	215,829	14,072
		Fall-run	Hatchery	36	185,142	0.00	1.06	9.64	0.00	0.30	1.55	6,665,112	90,646
			Delta[2]	23	145,292	0.00	0.70	5.25	0.00	0.20	1.31	3,341,716	30,075
Totals				**427**								**70,864,458**	**255,947**
Average Number of Fish per Release Group					**166,000**	**Average loss for all fish released**				**0.4%**			

[1]Consists of Coleman Hatchery releases from 1993-1997 and Livingston Stone releases from 1998-2009

[2]Consists of releases into the Sacramento River at locations between Red Bluff Diversion Dam and Sacramento and in the Delta

[3]Consists of releases into the San Joaquin River near Mossdale and downstream in the Delta

9.2.1.8 *Salvage as an index of survival rather than of mortality*

Estimates of smolt survival through the Delta have been derived primarily from CWT-marked test groups of juvenile hatchery Chinook released in or near the Delta. Since 2006, technological advances in miniaturization of signal-emitting tags (radio and acoustic) have made it possible to track individual smolts passing through the Delta. This has allowed for more precise estimates of survival and analysis of the factors affecting smolts within the Delta. Notwithstanding this improved technology, fish management agencies have continued to use the number of fish salvaged at the CVP and SWP fish salvage facilities as their primary index of mortality related to SWP and CVP exports.

As described in greater detail below, we undertook a series of analyses using data on smolt salvage to test the traditional hypothesis that increased smolt salvage de facto leads to increased mortality to smolts attributable to export pumping. Contrary to the traditional hypothesis, we determined that increasing salvage at the SWP and CVP fish facilities primarily corresponds with increased abundance of smolts in the Delta, rather than overall increased smolt mortality. We determined that mortality is better estimated by accounting for the proportion of smolts using the various routes through the Delta rather than simply calculating mortality based upon salvage.

Recent tagging studies of Chinook smolt passage through the Delta (Newman 2008) show that fish salvage at the export pumps is not a meaningful indicator of smolt mortality as they pass through the Delta (Figure 9-19). Direct mortality at the export facilities has generally been calculated as a multiple of the number of fish salvaged. The number of fish saved (salvaged) has been used to estimate the number that died, and thus rates of salvage have become synonymous with fish mortality. If salvage rate is an index of mortality rate (per the hypothesis), then independent estimates of smolt survival should show that survival decreases as salvage increases. Such comparisons can be and have been made for CWT smolts. However, these comparisons show no relationship between salvage and juvenile survival rates (Figure 9-19).

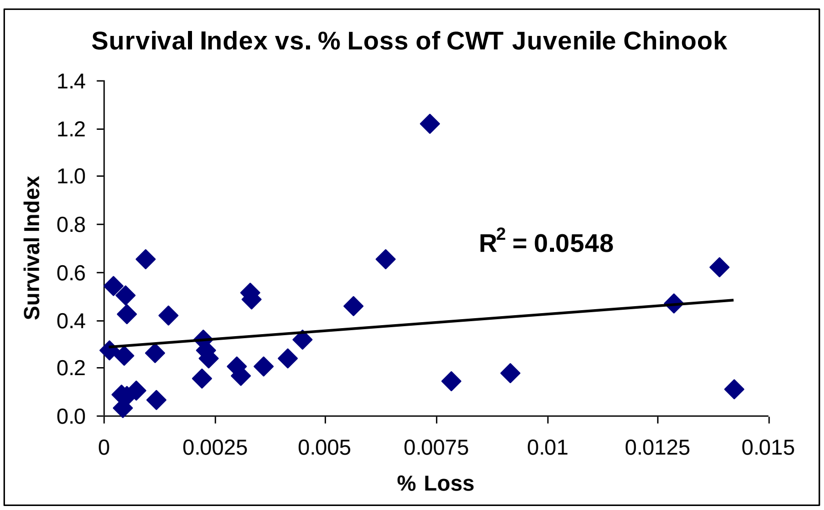

Figure 9-19. Relationship of Chinook smolt survival through the Delta to expanded percent loss of the same CWT groups at the CVP and SWP fish facilities. Data and survival estimates from Newman (2008) for late-fall CWT groups released during fall – winter in the Sacramento River Delta. The relationship is not significant.

The size and timing of juvenile salmon captures at Chipps Island correspond to seasonal trends in salmon abundance reflected in salvage at the fish facilities. When more smolts are passing through the Delta (as indexed by Chipps Island Trawl catches), more smolts are salvaged (Figure 9-20). Analyses of salmon monitoring data also show that once the effect of smolt abundance passing through the Delta is accounted for, the remaining variation in salvage rates is statistically related to Delta inflow and water temperature, but only weakly or not at all to export volume. For Sacramento River smolts, the effect of exports was insignificant (P = 0.17) and for San Joaquin River smolts, the effect was marginally significant (P = 0.06), but small.

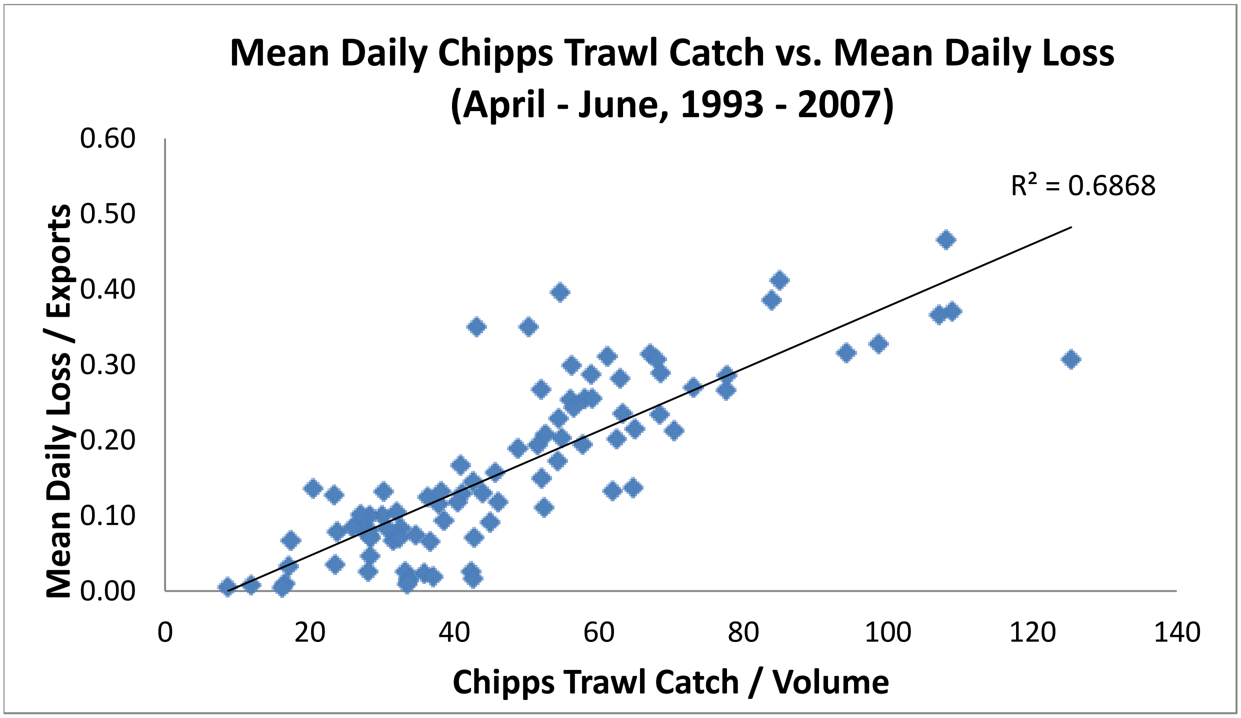

Figure 9-20. Correlation of expanded loss at the Delta pumps to the index of smolt abundance entering San Francisco Bay (Chipps Trawl catch/day). Each point is a monthly average across 1993-2007 for all juvenile Chinook combined. This demonstrates that catch at fish facilities reflects abundance of fish surviving through the Delta.

We used CWT releases of Chinook salmon from Coleman National Fish Hatchery over the 10-year period 1997-2006 to statistically analyze the factors that related to the proportion of those fish that were salvaged. The highest correlation was a positive relationship with catch of the CWT in Chipps trawl, followed by a positive relationship to Sacramento flow and a negative relationship to San Joaquin flow. With these variables in the model, the added effect of export volume was insignificant (P= 0.17). The sign and magnitude of effect from these variables indicates that higher survivorship (not mortality) through the Delta (indicated by catches in Chipps trawl) leads to more fish arriving at the export facilities, and this is further increased as flows in the Sacramento increase, but decreases as flows in the San Joaquin River increase. These opposite flow effects from the two rivers reflect their effects on Delta hydrodynamics–the proportion of flow arriving at the pumps from the Sacramento River increases as the ratio of Sacramento flow is more dominant and decreases as San Joaquin flow becomes more prominent.

Similarly, the analyses showed that the proportion of San Joaquin CWT fish recovered increases as their catch in the Chipps trawl increases and as the proportion of San Joaquin flow entering Old River increases, but decreases as temperature and flow in the San Joaquin increases. Again the signs and magnitude of effects are intuitive: Old River flows directly to the export facilities, while the San Joaquin River, after passing the Head of Old River, guides fish further away from the export facilities. As was true for Sacramento CWT fish, the salvage rate of San Joaquin CWT fish was not significantly correlated to export rate after the effects of these other variables was accounted for.

Conclusions from these analyses include:

- Numbers of fish salvaged at the south Delta export facilities provide an index of smolt survivorship to San Francisco Bay;
- Survivorship to the Delta has a much stronger influence on salvage than does export rate; and
- Parsing of fish salvage abundance into (1) numbers contributed by smolt abundance, and (2) numbers drawn in by pumping will require a mechanistic analysis of how fish choose pathways through the Delta.

The DPM provides the needed integration of mechanisms and makes it possible to link route choices and survival in each route to flow and water operations in the Delta. The proportion of smolts that take different routes through the Delta is presently being analyzed for the acoustic tagging studies conducted in 2012. The 2012 data will expand the number of channel junctions within the Delta for which the proportionate routing of smolts can be estimated, and this information will be incorporated into the Delta Passage Model during the fall of 2012. Then, it will be possible to estimate the magnitude of indirect mortality related to pumping volume.

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10 Ocean Conditions

Ocean conditions are an important factor impacting salmonid survival and abundance in terms of both successful rearing and ocean harvest of adults (Lindley *et al.* 2009). Changes in ocean conditions can have a major impact on salmonids that cannot be addressed through Delta or upstream flow changes.

Chinook salmon and steelhead spend a considerable proportion of their lifecycle inhabiting coastal marine waters. See Tables 1-1 and 1-2. Many salmonids enter the ocean as young of the year juveniles and reside in the marine habitat for a period of several years or more (Williams 2006). The survival of smolts at the time of ocean entry is thought to be the most critical phase for salmon during their residence in the ocean (Quinn 2005).

During their ocean residency, juvenile and sub-adult salmonids forage and grow, and food availability is a critical factor influencing their growth and survival. Food availability in coastal marine waters varies in response to a number of factors that include coastal upwelling and ocean temperatures and currents. Coastal upwelling and other oceanographic processes that influence productivity are characterized by cyclic patterns with recurrence intervals that may vary from years to decades. For example, ocean productivity was very low in the Gulf of the Farallones in 2005 and 2006, which was correlated with extremely low adult salmon returns in 2007, 2008, and 2009 that were thought to reflect poor food availability and high juvenile mortality in the ocean (Lindley *et al.* 2009). In response to the low numbers of adult salmon in the population the commercial and recreational fisheries were curtailed to protect the weak stocks.

Ocean upwelling and productivity have been good in recent years and the estimated number of adult fall-run Chinook salmon in coastal waters in 2012 is among the highest levels (approximately 800,000 adults) in the past decade. A similar pattern in adult abundance and escapement was observed in 2000 when the Central Valley adult escapement of 478,000 fish was the highest level since the early 1950s. Escapement in 2000 was exceeded in 2001 when approximately 600,000 adult salmon returned to the Central Valley and again in 2002 when adult escapement was approximately 850,000 fish (GranTab 2011).

The decline in adult Chinook salmon escapement in 2007 raised a number of concerns about factors contributing to the observed decline. In 2009, NMFS scientists (Lindley *et al.* 2009) compiled and analyzed information to determine whether ocean conditions were a major factor contributing to the observed decline in 2007 salmon adult escapement. The NMFS scientists found that ocean conditions were poor for salmon growth and survival in 2005 and 2006 and were the primary cause of the decline. Indices of ocean production, water currents, and oceanographic conditions such as upwelling, as measured by the Wells Ocean Productivity Index and the Northern Pacific Oscillation Index, indicated that conditions for salmonids declined substantially in the mid-2000s. Salmon stocks outside of the Bay-Delta estuary—and thus outside the influence of Delta environmental conditions and CVP/SWP export operations—also reported declines during the same period, including a marked reduction in coho salmon populations in Oregon and northern California. The NMFS and other studies of ocean conditions in the mid-2000s, along with the corresponding declines in coastal coho salmon populations, provide strong evidence that poor ocean conditions were the major factor affecting adult salmon escapement in 2007.

Observations from adult escapement in 2008 of approximately 72,000 adults and 2009 when adult escapement was approximately 53,000 adults demonstrate that coastal productivity has a strong influence on juvenile salmon growth and survival in the ocean. When coastal conditions are poor, survival declines and adult abundance is low. In contrast, the estimated adult abundance in 2000-2002 and 2012 indicates that salmon populations continue to be robust and have the capacity to produce large numbers of adults in those years when ocean conditions and productivity are good for juvenile rearing. Variability in ocean rearing conditions contributes substantially to the overall population dynamics of Central Valley salmonids and to variability in adult production and escapement among years (Lindley *et al.* 2009, Wells *et al.* 2008).

In addition to variability in ocean productivity, which affects juvenile growth and survival in the ocean, juvenile and sub-adult salmonids are also vulnerable to predation by fish, birds, and marine mammals during their ocean residency. Variation in ocean temperatures and current patterns affect the species composition and abundance of predatory fish that potentially prey on juvenile and sub-adult salmonids. There is very little quantitative information regarding the movement patterns and survival of juvenile salmonids in the ocean. Recent advances in acoustic tagging technology have provided monitoring tools that are expected to provide greater insight into the movements of juvenile salmonids in coastal areas as well as improved information about the magnitude of predation mortality as a factor affecting salmonid survival and abundance during their ocean rearing phase.

Fall-run Chinook salmon support an important commercial and recreational fishery. However, Central Valley salmon populations appear to overlap substantially in their distribution in the ocean and, therefore, there is the risk that protected winter-run and spring-run Chinook salmon will also be harvested.

To address the concern regarding incidental take of protected salmon in the coastal fishery, NMFS recently completed a revised Biological Opinion for ocean salmon harvest (NMFS 2010b). The Pacific Fishery Management Council (PFMC) has also reduced ocean salmon harvest in recent years (PFMC 2012).

Ocean fisheries harvest management objectives are designed to allow harvest of Chinook salmon that are in excess of the goals for spawner abundance (escapement) to the Sacramento and San Joaquin river systems (Boydstun 2001). These goals are established by the PFMC and are expressed as a range of 122,000 to 180,000 hatchery and natural Chinook returning to the Central Valley (CV). Thus, harvest regulations are more liberal when abundance is predicted to exceed this range and is increasingly restricted as abundance approaches the lower limit of the range.

As a result, the fraction of Central Valley Chinook salmon harvested in the ocean varies widely across years. The exploitation rate (harvest) has ranged from over 80 percent in the early 1990s to only 1 percent in 2009 (Figure 10-1). The effect of variable harvesting is even greater when the impact is viewed as the fraction of fish that is allowed to survive rather than as the fraction that is harvested. The fraction allowed to survive has ranged over four-fold, from 15 percent to 60 percent, even excluding the much greater increases in survival from curtailed harvest during 2008-2010 (Figure 10-2; ChinookProd 2011).

Mandated reductions in ocean salmon harvest are expected to provide improved protection for winter-run and spring-run Chinook salmon, and also contribute to increased escapement of all salmon runs to Central Valley rivers (NMFS 2010b). Since steelhead are not caught in the commercial or recreational fishery, changes in harvest regulations for salmon are not expected to have any effect on adult steelhead abundance or escapement.

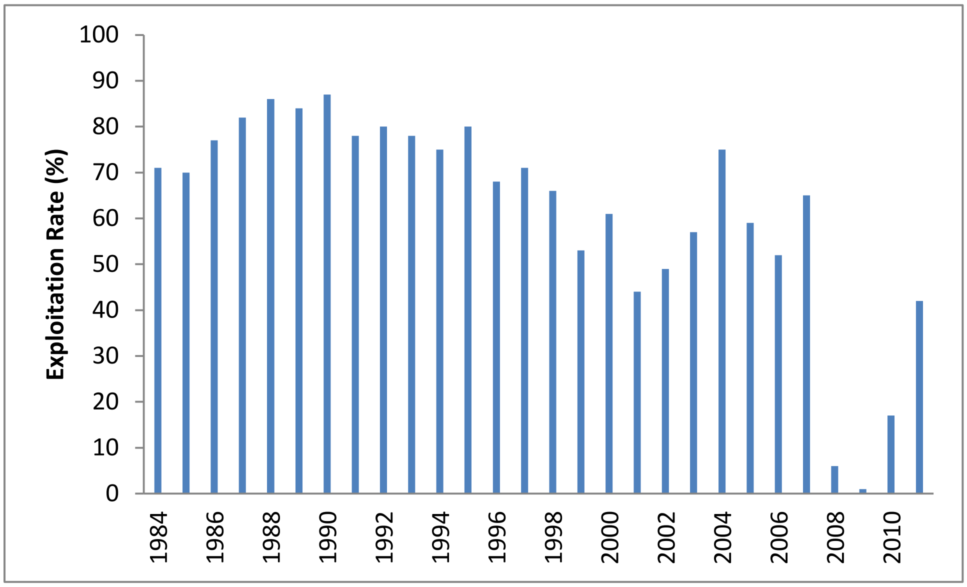

Figure 10-1. Sacramento River fall-run Chinook salmon exploitation rates (Source: PMFC 2012).

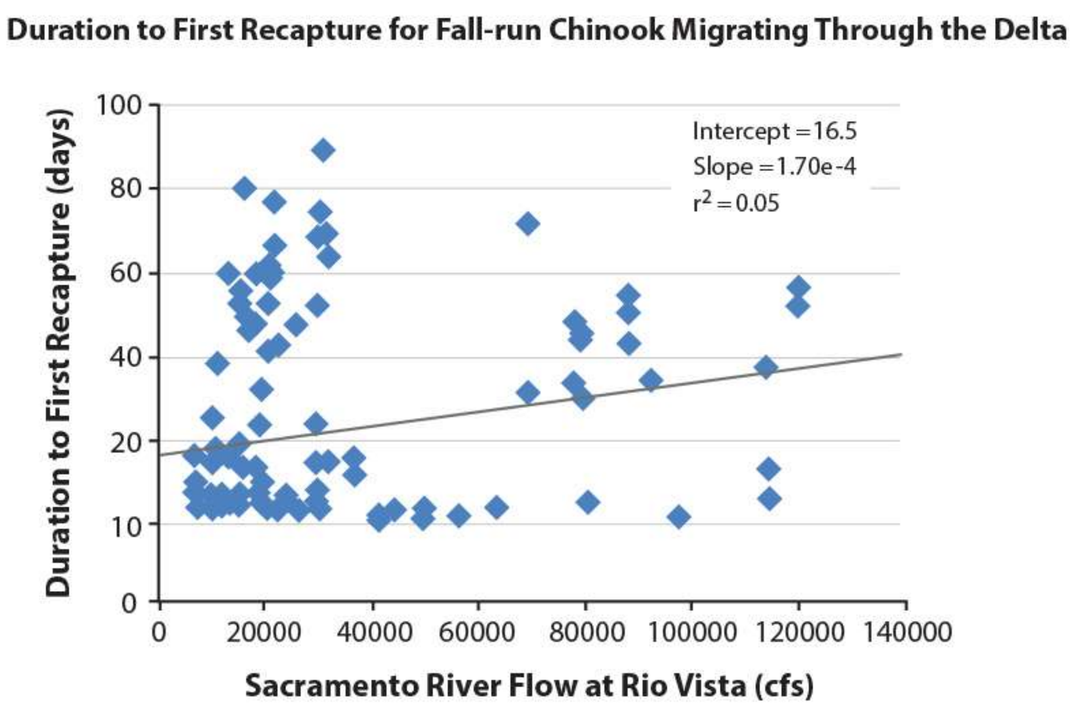

Figure 10-2. The Sacramento Index (SI) and relative levels of its components. The Sacramento River fall Chinook escapement goal range of 122,000-180,000 adult spawners is noted on the vertical axis.

The ocean fishery off California's coast for Central Valley Chinook salmon is a mixed-stock fishery reflecting a combination of runs of salmon as well as wild and hatchery produced Chinook salmon. Fall-run Chinook salmon are produced in greatest numbers in Central Valley hatcheries and are the primary target of the ocean fishery. Currently, a constant fractional marking program is employed in which 25 percent of the salmon produced in Central Valley hatcheries are CWT and their adipose fin is clipped as an external mark. Other than those fish with an adipose fin clip commercial and recreational anglers have no way of determining whether a salmon that has been caught was produced in a hatchery or was a wild fall-run, winter-run, late fall-run, or spring-run salmon. Fishery regulations currently do not specify that only hatchery produced salmon can be harvested.

Because hatcheries have been efficient in producing juvenile fall-run Chinook salmon, harvest regulations in past years have allowed very high harvest rates that, while theoretically sustainable by hatchery operations, exceed the harvest rate that a wild salmon population can support. In Washington, salmon harvest in the ocean is limited to only hatchery produced fish through use of a mark-select fishery. In a mark-select fishery only adult salmon that have an adipose fin clip can be harvested. Wild fish are reflected by an intact adipose fin and are required to be released.

Pyper *et al.* (2012) evaluated the potential effects of a mark-select fishery on ocean harvest and escapement of Sacramento River fall-run Chinook salmon. Based on model results , Pyper *et al.* (2012) estimated that actual adult escapement would have increased approximately 119 percent on average over the 1988-2007 period had a mark-select fishery been in place. During the recent period when fishing regulations have more strictly controlled the harvest rate (Figures 10-1 and 10-2), the estimated increase in natural-origin salmon escapement ranged from 24 to 48 percent depending on model assumptions (Pyper *et al.* 2012). The model results also showed that implementing a mark-select harvest regulation would result in reductions in commercial and recreational ocean harvest, with the magnitude of impact to the fishery depending on the proportion of the ocean salmon population composed of hatchery-origin salmon.

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Attachment A: Floodplain Habitat Benefits for Aquatic Productivity and Native Fishes

Introduction

This appendix reviews the benefits that floodplains can provide the Sacramento-San Joaquin Delta ecosystem. Natural floodplains are one of Earth's most productive and biologically diverse ecosystems (Tockner and Stanford 2002). Floodplains can provide ecosystem benefits at several spatial scales. Habitat mosaics within the floodplain, such as riparian forest, support a wide array of species including birds (Gardali *et al.* 2006, Golet *et al.* 2008). When inundated, the floodplain also benefits species that can directly access these aquatic habitats, such as fishes that spawn or forage on the floodplain (Moyle *et al.* 2007). Finally, floodplains can potentially provide regional benefits by exporting food resources such as phytoplankton to downstream systems (Sommer *et al.* 2004, Ahearn *et al.* 2006, Lehman *et al.* 2008).

Key attributes of functional floodplains

Seasonal flooding and hydrological connectivity are prerequisites for ecologically functional floodplains (Junk *et al.* 1989, Mahoney and Rood 1998, Galat *et al.* 1998, Tockner *et al.* 2000, Tockner and Stanford 2002, Bunn and Arthington 2002, Ward 2002, Rood *et al.* 2005, Kondolf *et al.* 2006). A range of hydrologic events is necessary to maintain the ecological integrity of riverine aquatic ecosystems (Poff *et al.* 1997, Bunn and Arthington 2002). Key attributes of ecologically functional floodplains include: (1) hydrologic connectivity between the river and the floodplain, (2) a variable flow regime that reflects seasonal precipitation patterns and retains a range of both high and low flow events, and (3) sufficient spatial scale to encompass dynamic processes and for floodplain benefits to accrue to a meaningful level (Opperman *et al.* 2010).

Most Central Valley floodplains, however, are severed from their rivers by levees, channelization and flow regulation (Mount 1995). Infrastructure and management for water supply and flood control have altered river hydrologic and geomorphic function by eliminating spring flooding, reducing variability of flows, and altering sediment transport (TBI 1998, Williams *et al.* 2009). This river-floodplain disconnect affects functional attributes of floodplains, including reduced nutrient replenishment and associated food web development, and decreased variability of flood-dependent habitats (Jeffres *et al.* 2008, Opperman *et al.* 2010).

Different floodplain processes emerge at increasing levels of floods, which Opperman and others (2010) categorized as floodplain activation, floodplain maintenance, and floodplain resetting floods. Floodplain activation flows (FAF) are frequent (1-3 year recurrence interval), small-magnitude floods that reconnect the river and floodplain, often for long duration and several times in a season (Opperman *et al.* 2010). The FAF is the smallest flood pulse event that initiates substantial beneficial ecological processes (Williams *et al.* 2009). Floodplain maintenance floods are higher magnitude and are capable of bank erosion and sediment deposition on the floodplain (Florsheim and Mount 2002, Opperman *et al.* 2010). Finally, floodplain resetting floods are rare (<5 percent exceedance probability), very high magnitude events that produce extensive geomorphic change, such as scouring of floodplain surfaces and channel avulsion (Opperman *et al.* 2010).

Ecological processes are more dependent on duration and timing of floodplain inundation than simply magnitude of flows (Poff *et al.* 1997, Booth *et al.* 2006, Opperman *et al.* 2010). Frequent, prolonged inundation is essential for activating key processes of an ecologically functional floodplain, in both tropical (e.g., Junk *et al.* 1989) and temperate systems (Williams *et al.* 2009, Opperman *et al.* 2010). During periods of inundation, floodplains provide very different habitat conditions than found in the adjacent river channel. As water spreads onto the floodplain, velocity slows and sediment drops out of suspension. Because floodplain water is often less turbid than river water, inundated floodplains can support greater rates of photosynthesis from aquatic vascular plants and algae (including both attached algae and phytoplankton) (Tockner *et al.* 1999, Ahearn *et al.* 2006). This enhanced primary productivity in turn supports high secondary productivity (Junk *et al.* 1989, Grosholz and Gallo, 2006).

Floodplains in the Sacramento-San Joaquin Delta Region

The functional floodplain concepts are illustrated by studies of the Yolo Bypass (e.g., Sommer *et al.* 2001a&b, 2003), Cosumnes River (e.g., Mount *et al.* 2003, Swenson *et al.* 2003, Jeffres *et al.* 2008), and Sacramento River (e.g., Williams *et al.* 2009). These concepts are currently being applied to restoration of the upper San Joaquin River, such as the floodplain activation flow and design of seasonal floodplain habitat to benefit migrant rearing of juvenile Chinook salmon (*Oncorhynchus tshawytscha*).

The Yolo Bypass

The 24,000-ha Yolo Bypass is the largest floodplain of the Sacramento-San Joaquin Delta (Sommer *et al.* 2003). This engineered floodplain (61-km long and 3-km wide) is not immediately adjacent to a main river, but rather receives floodwaters through discrete locations. The floodplain is inundated during winter and spring in about 60 percent of years. During high flow events, Yolo Bypass can have a discharge of up to 14,000 m^3/s, representing 75 percent of total Sacramento River basin flow. Under typical flood events, water spills into Yolo Bypass at Fremont Weir when Sacramento basin flows surpass approximately 2000 m^3/s. At higher basin flows (>5000 m^3/s), Sacramento Weir also spills. When flood waters recede, the basin empties through a permanent tidal channel along the eastern edge of Yolo Bypass. The floodplain is relatively well drained, but several isolated ponds remain perennially inundated (Feyrer *et al.* 2004). The Yolo Bypass supports fish and waterfowl in seasonally inundated habitats during winter and spring, and agriculture during summer (Sommer *et al.* 2001b).

Cosumnes River

The Cosumnes River drains from the Sierra Nevada into the eastside of the Delta. The Cosumnes River is one of the few Central Valley rivers without a major dam regulating its flows. As such, the river still maintains a variable seasonal flow regime typical of Mediterranean systems, experiencing winter flooding from rainfall (November-February) with peak flows of up to 2,650 m^3/s (1997), smaller floods fed by snowmelt (March-May), and low to no late summer and fall flows (Booth *et al.* 2006). Levees constructed starting in the late 1800s still constrain much of the river channel (Florsheim and Mount 2002). The lowest reach of the river is influenced by freshwater tides of the Delta. Currently, over 688 ha of restored and remnant riparian forest, including stands of valley oak (*Quercus lobata*) forest, occur along the lower Cosumnes River.

At the Cosumnes River Preserve, approximately 100 hectares of floodplain were functionally reconnected to the river when levees were breached intentionally in October 1995 and by floods in January 1997 (Swenson *et al.* 2003). Previously, the river overtopped its banks established connectivity every 5 years when flows exceeded approximately 50 m^3/s. After the 1995 breach, this occurred earlier and more frequently (1.5 year recurrence interval) at half that flow (25 m^3/s) (Florsheim and Mount 2003, Florsheim *et al.* 2006). Variable floods produced a range of geomorphic and ecological outcomes. Flows exceeding 100 m^3/s deposited and eroded sediment on the floodplain. The January 1997 floods (2,650 m^3/s, 150-year recurrence interval) caused extensive levee failure along the river. These flows correlate to the floodplain activation, floodplain maintenance, and floodplain resetting flows (Opperman *et al.* 2010).

Sacramento River

Much of the Sacramento River no longer has frequently inundated active floodplains. This reflects the fact that small, frequent spring flood events have been reduced since the construction and operation of large dams in the Sacramento Valley (Williams *et al.* 2009), as well as levee construction and channel incision. Williams and others (2009) defined the Floodplain Activation Flow (FAF) for Sacramento River lowland floodplains, in particular the confined leveed reaches downstream of Colusa and are adjacent to the largest area of former and potentially restorable floodplain in the system. The FAF must occur with a suitable duration and timing to produce identifiable ecological benefits, must allow hydraulic connectivity between the river and the floodplain during the period of flooding, and occur with sufficient frequency to make ecological benefits meaningful inter-annually. The FAF for the lower Sacramento River is the river stage that is exceeded in at least 2 out of 3 years and sustained for at least 7 days between March 15 and May 15 (Williams *et al.* 2009).

Williams and others (2009) concluded that the biggest opportunities for floodplain restoration lie in the bypasses. Levee setbacks on the Sacramento River for improved flood conveyance could increase the amount of active floodplains, but only with increased release of small spring flood pulses from upstream reservoirs or grading of the newly-established floodplains down to the current FAF stage. A recent example that applied the FAF concept is the flood control levee setback project at the confluence of the Bear and Feather Rivers, including a swale excavation to improve river-floodplain connectivity and reduce fish stranding (Williams *et al.* 2009).

Floodplain Benefits

Riparian Forest and Scrub Communities

Disturbance events such as floods provide conditions necessary for the regeneration of riparian tree species (Mahoney and Rood 1998, Mount *et al.* 2003, Rood *et al.* 2005). Floods create diverse topography on the floodplain. In 1995, high flows brought a pulse of sediment onto the floodplain in finger-like deposits up to 5 m deep and a few hundred meters long. Finer silts remained in suspension longer and were deposited in thin layers across the floodplain (Florsheim and Mount 2002, Florsheim *et al.* 2006). Subsequent floods reworked floodplain sediments and scoured out channels nearly 4 m below the original elevation (Florsheim and Mount 2002).

Riparian plant communities are shaped by inundation dynamics (Junk *et al.* 1989, Mahoney and Rood 1998) and height above the water table (Stromberg *et al.* 1991, Marston *et al.* 1995), which are both influenced by floodplain topography (Florsheim and Mount 2002). The habitat mosaic at the restored Cosumnes floodplain included cottonwood and willows on elevated sandbars, herbaceous vegetation in scoured areas, and emergent wetland plants in some permanent floodplain ponds. The varied physical structure of riparian vegetation supports diverse wildlife in the Central Valley, including many songbird species (Gardali *et al.* 2006, Wood *et al.* 2006, Golet *et al.* 2008).

Aquatic Productivity

Primary production within the Delta estuary is inherently low because of high turbidity and low light levels, rather than nutrient limitations (Jassby *et al.* 2002, Lopez *et al.* 2006). Detrital inputs dominate the organic matter supply of the riverine and estuarine systems, but much of this is not readily bioavailable except via a microbial pathway (Sobczak *et al.* 2002 and 2005). Phytoplankton comprise a small fraction of the Delta's organic matter supply, yet they provide the most significant food source for zooplankton (Müller-Solger *et al.* 2002, Sobczak *et al.* 2005). Stocks of zooplankton have declined significantly since the 1970s (Orsi and Mecum 1996). The declining productivity of pelagic food webs has been proposed as a contributing factor to population declines of native fishes (Bennett and Moyle 1996, Baxter *et al.* 2008, Glibert 2010).

In contrast, Central Valley floodplains can produce high levels of phytoplankton and other algae, particularly during long-duration flooding that occurs in the spring (Sommer *et al.* 2004, Ahearn *et al.* 2006). The shallow water depth and long residence time in floodplains facilitate settling of suspended solids, resulting in reduced turbidity and increased total irradiance available for phytoplankton growth in the water column (Tockner *et al.* 1999). At the Cosumnes River Preserve, the inundated floodplain progressed from a physically driven system when connected to the river floods, to a biologically driven pond-like system with increasing temperature and productivity once inflow ceased (Grosholz and Gallo 2006). Periodic small floods boosted aquatic productivity of phytoplankton (measured as chlorophyll a) by delivering new pulses of nutrients, mixing waters, and exchanging organic materials with the river (Ahearn *et al.* 2006). Aquatic productivity was greater in floodplain ponds than in river sites (5-10 times greater chlorophyll-a values and 10-100 times greater zooplankton biomass) (Ahearn *et al.* 2006, Grosholz and Gallo 2006). Zooplankton biomass increased rapidly following each flood event to a peak approximately 7 – 25 days after disconnection from the river, with highest observed values (approximately 1,000 – 2,000 mg/m^3) at approximately 21 days (Grosholz and Gallo 2006).

As reviewed by Lehman and others (2008), phytoplankton produced on the floodplains are often higher in nutritional quality than phytoplankton found in rivers because they have a wider spherical diameter and thus higher carbon content (Hansen *et al.* 1994, Lewis *et al.* 2001). Diatoms and green algae, which are the dominant algal species in the Yolo Bypass (Lehman *et al.* 2008), have the highest cellular carbon content in the San Francisco Estuary phytoplankton community (Lehman 2000, Hansen *et al.* 1994). Laboratory trials with cladocerans indicate that phytoplankton was the most biologically available carbon source and produced the highest growth rate (Mueller Solger *et al.* 2002, Sobczak *et al.* 2002) (Figure A-1). Zooplankton may be food limited if phytoplankton concentrations drop below a level corresponding to 10 µg/L Chl *a* (Muller-Solger *et al.* 2002). This is important because these zooplankton are a primary food source for numerous Delta fish species.

Studies of the Yolo Bypass provide evidence of the incremental value of floodplain habitat to the conservation of large rivers (Sommer *et al.* 2001a&b, 2003). Chlorophyll a levels were significantly higher in the floodplain than in the river, and were negatively associated with flow. These results were consistent with longer hydraulic residence times, increased surface area of shallow water, and warmer water temperatures. Copepods and cladoceran densities were similar in the river and its floodplain, and were mostly negatively associated with flow. Chironomids were positively correlated with flow (discharge and flow velocity); these organisms were one to two orders of magnitude more abundant in the Yolo Bypass floodplain than the adjacent Sacramento River channel (Sommer *et al.* 2001a).

Providing river–floodplain connectivity can enhance production of lower trophic levels at relatively rapid time scales (Sommer *et al.* 2004). In the Yolo Bypass, some food web organisms can respond within days and attain high densities soon after inundation, including smaller fast-growing algae (e.g., picoplankton, small diatoms, nanofragellates), vagile organisms such as drift insects, and organisms associated with wetted substrate such as chironomids. These organisms, particularly chironomids, provide a food source to fish that is available prior to the development of food web productivity associated with long residence times (e.g., phytoplankton and zooplankton responses to inundation) (Sommer *et al.* 2004).

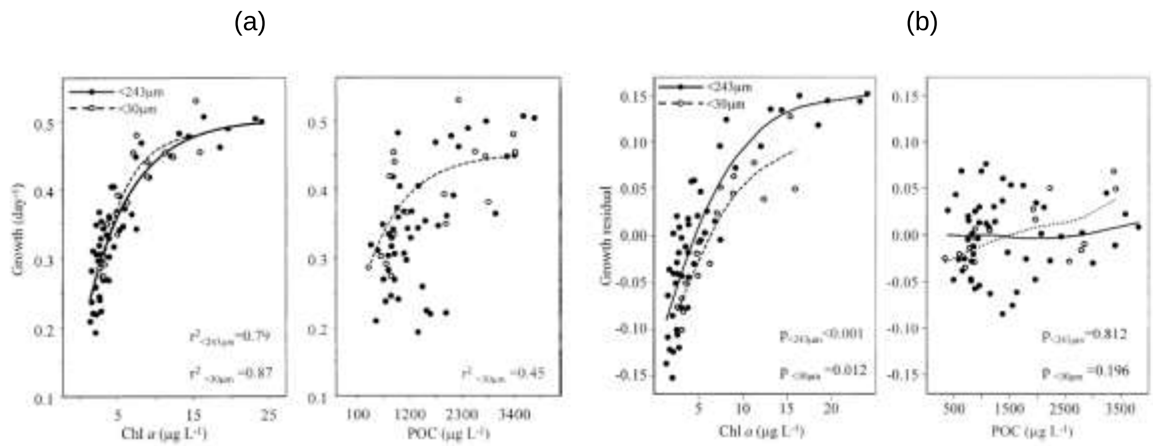

Figure A-1. Growth rate of *Daphnia* with algae and particulate organic carbon (POC). (a) Nonlinear regressions results of Daphnia growth rates against size fractionated Chl *a* and particulate organic carbon (POC). Growth rate is higher with algae (as measured by chlorophyll a concentrations) than with POC, (b) Partial residual plots of Chl *a* and POC effects on growth from a general additive model. Growth is higher with larger algae (seston <243 μm) than small (<30 μm). From Mueller-Solger *et al.* 2002.

Consequently, a potential benefit of floodplain restoration is an increase in the productivity of food webs that support Delta fish species (Ahearn *et al.* 2006). For example, Delta smelt and longfin smelt are two species dependent on zooplankton. Floodplains have been proposed as “productivity pumps” (Junk *et al.* 1989) that can export food resources, especially algae, to support food webs in downstream communities (Sommer *et al.* 2001b, Ahearn *et al.* 2006, Lehman *et al.* 2008). By periodically pulsing small “floodplain activation floods,” it may be possible to pump high concentrations of algae to downstream waters (Ahearn *et al.* 2006). Analysis of suspended algal biomass in the Cosumnes River channel and floodplain by Ahearn and others (2006) documented an increase in Chl *a* concentrations on the floodplain during periods of river-floodplain disconnection, and subsequent increase in Chl *a* in the river when connection was restored (Figure A-2). This illustrates export of floodplain-produced algae to downstream aquatic ecosystems during flood events.

Cloern (2007) used a nitrogen-phytoplankton-zooplankton model to illustrate how shallow habitats sustain fast phytoplankton growth and net autotrophy (photosynthesis exceeds community respiration), whereas deep, light-limited habitats within the Delta channels sustain low phytoplankton growth (Jassby *et al.* 2002) and net heterotrophy. Lopez and others (2006) found that surplus primary production in shallow habitats provided potential subsidies that likely supported zooplankton in neighboring habitats, except in areas heavily colonized by the invasive clam *Corbicula fluminea*. Lehman and others (2008) suggested that the quantity and quality of riverine phytoplankton biomass available to the aquatic food web could be enhanced by passing river water through a floodplain such as the Yolo Bypass during the flood season.

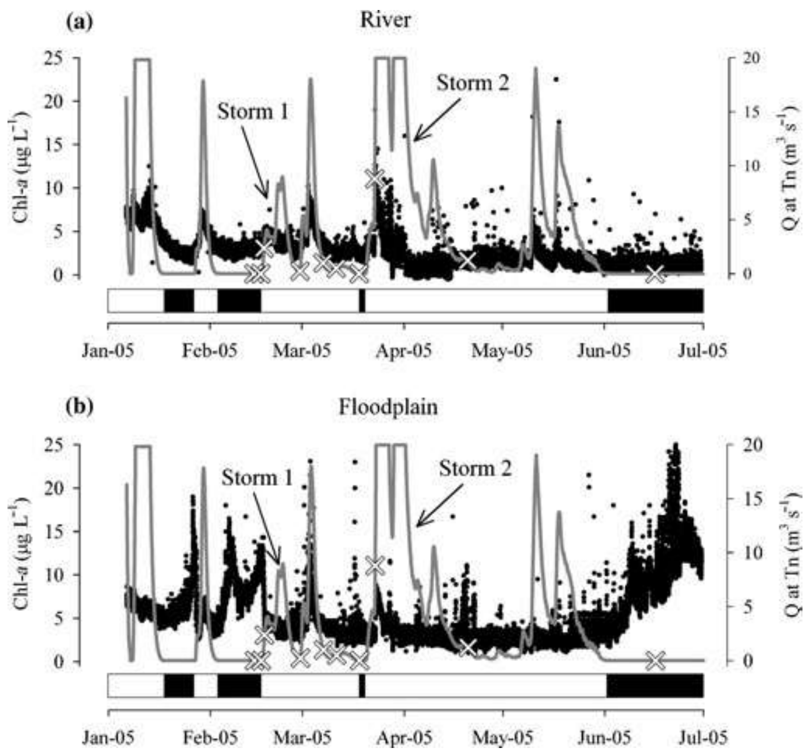

Figure A-2. Chlorophyll *a* (Chl *a*) concentration time series from (a) the river and (b) the floodplain pond at the Cosumnes River Preserve. Dates when Chl *a* distribution was measured are marked on the hydrograph with an "x". Black bars represent periods of disconnection with the river. The hydrograph plateaus on the three largest storms because the river discharge exceeded the rating curve. Note the increase in Chl *a* on the floodplain when the river and floodplain are disconnected. From Ahearn *et al.* 2006.

Spawning and Rearing Habitat for Native Fish

Floodplain inundation provides spawning and rearing habitat for fish that take advantage of the high productivity on the floodplain (Poff *et al.* 1997, Sommer *et al.* 2001a&b, Feyrer *et al.* 2004, Schramm and Eggleton 2006, Grosholz and Gallo 2006). During these periods of connection to the river, fish can move on and off the floodplain to spawn or forage (Moyle *et al.* 2007). Further, the low-velocity, shallow, and vegetated habitats of the floodplain serve as a refuge from the fast, turbid waters of the river during high flows (Sommer *et al.* 2001a, Jeffres *et al.* 2008).

The Sacramento splittail (*Pogonichthys macrolepidotus*) is perhaps the most floodplain-dependent species in the Delta (Sommer *et al.* 1997). Adults migrate onto the inundated floodplain to spawn on vegetation in February-March at both the Cosumnes floodplain (Moyle *et al.* 2007) and the Yolo Bypass (Sommer *et al.* 2004). Juveniles rear on the floodplain and depart when it drains in April-May, achieving better condition on the floodplain than in river habitats (Ribeiro *et al.* 2004).

Juvenile Chinook salmon also benefit from floodplains as foraging and refuge habitat. Juveniles migrate downstream onto floodplains in February to March to forage on the abundant invertebrates in the flooded vegetation, prior to emigrating to the sea (Moyle *et al.* 2007, Grosholz and Gallo 2006). At the Cosumnes River, growth rates of juveniles (mean length 54-55 mm) reared 54 days in enclosures were faster on ephemeral floodplain habitats (80-86 mm) than in the river (64 mm) (Jeffres *et al.* 2008) (Figures A-3 to A-4). The predominant prey was zooplankton in the floodplain ponds; benthic macroinvertebrates, amphipods and larval fish in submerged floodplain vegetation; and dipterans and coleopterans and insect drift in the river (Figure A-5).

At the Yolo Bypass, juvenile Chinook salmon grow larger and are in better condition than those in the river (Sommer *et al.* 2001a). Drift macroinvertebrates, such as chironomids and terrestrial invertebrates, are an important food resource for fish. Yolo Bypass salmon had significantly more prey in their stomach than salmon collected in the Sacramento River (Sommer *et al.* 2001a and 2004). Chironomids were the primary food resource for juvenile Chinook and were 1-2 orders of magnitude more abundant in the floodplain than the adjacent Sacramento River channel (Sommer *et al.* 2001a). However, the increased feeding success may have been partially offset by significantly higher water temperatures on the floodplain habitat, resulting in increased metabolic costs for young fish. The higher water temperatures were a consequence of the broad shallow shoals, which warm faster than deep river channels. Through bioenergetic modeling, Sommer and others (2001a) concluded that floodplain salmon had substantially better feeding success than fish in the Sacramento River, even when the prey data were corrected for increased metabolic costs of warmer floodplain habitat.

Figure A-3. Comparison of juvenile Chinook salmon reared 54 days at the Cosumnes River Preserve in (1) intertidal river habitat below the floodplain (left) and (2) floodplain vegetation (right). From Jeffres *et al.* 2008.

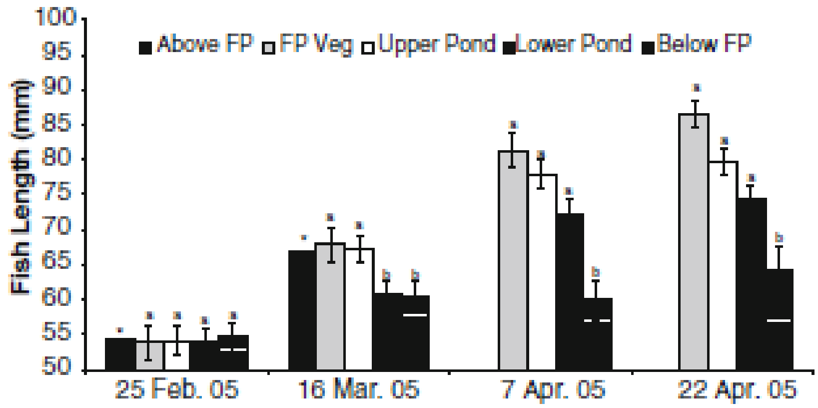

Figure A-4. Size (mean fork length ± standard error) of juvenile Chinook at the Cosumnes River Preserve reared in floodplain habitats (FP Veg, Upper Pond, and Lower Pond) and river channel sites (Above FP and Below FP) over four sampling sessions during the 2005 flood season. Habitats with different letters are statistically different. Asterisks indicate habitats not included in the statistical analysis. From Jeffres *et al.* 2008.

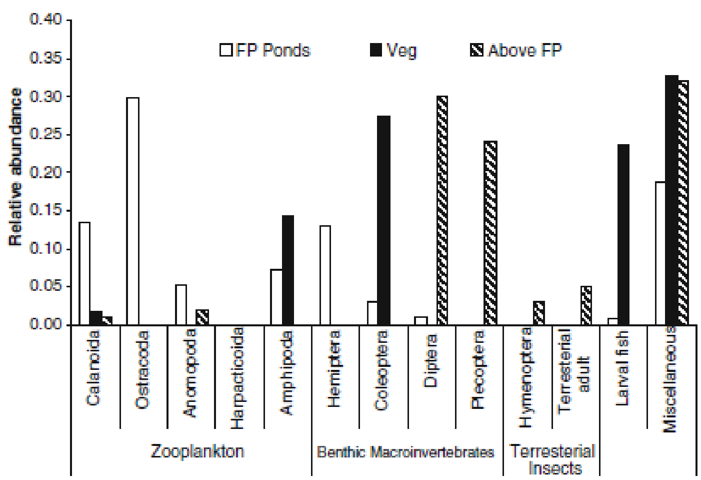

Figure A-5. Relative abundance of prey items in juvenile Chinook salmon on the Cosumnes River (1) floodplain ponds, (2) floodplain vegetation, and (3) river channel above (upstream) from the floodplain. From Jeffres *et al.* 2008.

Recreating the historical pattern of seasonal inundation can create habitat uniquely suited for floodplain-dependent native fishes and less hospitable for non-native fish. Native fish species that evolved with California's pattern of seasonal precipitation typically used the floodplain earlier in the year (February-May) (Figure A-6). In contrast, non-native species that evolved in temperate regions with year-round precipitation tend to arrive later and remain longer on the floodplain (April-July), spawn under warmer conditions (Moyle 2002), and are stranded more often when the floodplain drains and ponds dry out (Moyle *et al.* 2007). Fish stranding in shallow ponds at the end of the flooding season was a concern for floodplain restoration. However, remarkably few native fishes (splittail and Chinook salmon) were found in Cosumnes ponds once the river-floodplain connection was lost (Moyle *et al.* 2007). Similarly, juvenile Chinook salmon experienced low stranding rates in the Yolo Bypass Wildlife Area's managed wetlands after flood events (Sommer *et al.* 2005). It appears that floodplain-adapted fish species have the capacity to find their way off the floodplain before it becomes disconnected (Moyle *et al.* 2007).

Perennial aquatic habitat such as ditches and floodplain ponds are dominated by non-native fishes, as seen at the Cosumnes Preserve (Moyle *et al.* 2007) and the Yolo Bypass (Feyrer *et al.* 2004). Based on their observations at Cosumnes, Crain and others (2004) recommended that an optimal flood regime for native California fishes should include early season, cold water events that persist long enough for bursts in algal and invertebrate productivity, followed by spring draining of the floodplain before it warms and favors non-native species.

Predation is one mechanism that could lead to low native fish abundance in shallow-water habitats in the Delta. Some known predators of native Delta fish include striped bass, largemouth bass, and Sacramento pikeminnow (Nobriga and Feyer 2007). Predation is highest during spring (March-May) and during summer (June-August) (Nobriga and Feyrer 2007). Though there has been little investigation of predation on native fishes on floodplains, the observed seasonal use patterns and relative absence of piscivores suggest that floodplains offer native fishes a competitive advantage over non-native predators (Moyle 2007, Nobriga and Feyrer 2007). This differential pattern of habitat use is a rare opportunity where habitat restoration for native fishes does not simultaneously benefit non-native fishes that are potential predators or competitors.

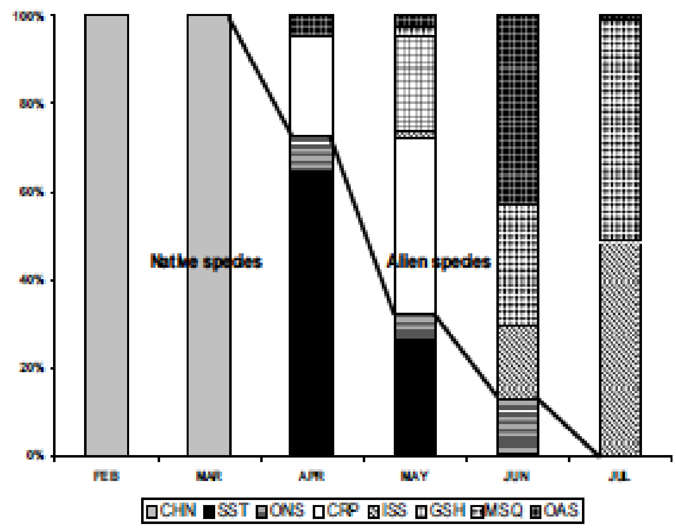

Figure A-6. Monthly percent abundance of juvenile fishes on the Cosumnes River floodplain for the year 2000. The line connects the dividing line between native and non-native (alien) species. Native fish were predominant early in the season. CHN = Chinook salmon, SST = splittail, ONS = other native species, CRP = carp, ISS = inland silverside, GSH = golden shiner, MSQ = western mosquitofish, OAS = other alien species (From Moyle *et al.* 2007).

Conclusion

Floodplains can provide a variety of benefits at different spatial scales depending on hydrologic regime, connectivity between river-floodplain habitats, and life history requirements of species. The magnitude of benefit for foodwebs and fish depends on the area that experiences frequent inundation (Opperman *et al.* 2010). The restored floodplain (100 ha) at the Cosumnes River can provide local benefits, but it is likely too small to accrue meaningful benefits for the broader Delta estuary (Opperman *et al.* 2010). Larger floodplain areas such as the Yolo Bypass (24,000 ha), however, have the capacity to influence fish at the population scale. For example, the duration of inundation of the Yolo Bypass is a strong predictor of year-class strength for splittail for the entire Central Valley and Delta system (Sommer *et al.* 1997, Feyrer *et al.* 2008). Longer inundation periods of weeks can maximize foodweb productivity, but even short inundation periods of days can provide ecosystem benefits (Sommer *et al.* 2004). For a food-limited system such as the Delta, it is reasonable to expect that any subsidy of food from floodplains has the potential to benefit the Delta foodweb.

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Attachment B

Table B-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Shasta Division/Shasta & Keswick Dams	Sacramento River water temperature objectives	<56°F, April 1 – Sept. 30; <60 °F, Oct. 1 – 31 at RBDD[1]	State Water Resources Control Board (SWRCB)
		< 56°F Keswick Dam to Bend Bridge with initial targets, based on May 1 Shasta cold water (<52°F) volume, as follows[2]: • >3.6 MAF - Bend Bridge • 3.3 - 3.6 MAF - Jellys Ferry • <3.3 MAF - Balls Ferry	National Marine Fisheries Service (NMFS)
	Sacramento River Temperature Task Group (SRTTG)[3]	Convened to formulate, monitor & coordinate annual temperature control plans	SWRCB
	Shasta Reservoir target minimum end of year carry-over storage (1.9 MAF)	To increase probability that sufficient cold water pool will be available to maintain suitable Sacramento River water temperatures for winter-run Chinook the following year	NMFS
	Sacramento River flows (releases from Keswick Dam)	Minimum flows: 3,250 cfs October 1 – March 30	SWRCB, CVPIA
	Flow ramp down rates from Shasta Dam	• Apply following schedule between July 1 and March 31[4]: • Reduce flows sunset to sunrise only • ≥6,000 cfs; < 15%/night and 2.5%/hour • 4,000 to 5,999 cfs; <200 cfs/night and 100 cfs/hour • 3,250 to 3,999 cfs; <100 cfs/night	NMFS

[1] Allows flexibility when water temperatures cannot be met at RBDD. Temperature management plan developed each year by the Sacramento River Temperature Task Group (SRTTG).

[2] Based on temperature management plan developed annually by the SRTTG.

[3] The SRTTG is composed of representatives of SWRCB, NMFS, FWS, DFG, Reclamation, WAPA, DWR & Hoopa Tribe.

[4] Variations to ramping rate schedule allowed under flood control operations

Table B-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Red Bluff Diversion Dam	Gate operations	Gates raised from September 15 to May 14[5]	NMFS
	Sacramento River Water temperature objectives	<56°F, April 1 – Sept. 30; <60 °F, Oct. 1 – 31	SWRCB
Wilkins Slough	Navigation Flow Objective	Minimum of 5,000 cfs at Wilkins Slough gauging station on the Sacramento River; can relax standard to 3,500 cfs for short periods in critical dry years[6]	USBR
Oroville/Feather River Operations	Feather River minimum flows	600 cfs below Thermalito Diversion Dam when Lake Oroville elevation <733 ft MSL increasing to 1,000 cfs April through September if Lake Oroville elevation >733 ft MSL; Flows generals kept < 2,500 cfs August through April to avoid stranding salmonids	DWR & DFG Agreement
American River Division/Folsom & Nimbus Dams	American River minimum flow standards	Minimum 250 cfs January 1 to September 14 & 500 cfs September 15 to December 31 measured at the mouth of American River	SWRCB
	American River temperature objectives	Reclamation to develop, in coordination with the American River Operations Group and NMFS, annual water temperature control plan to target 68°F at Watt Avenue Bridge	NMFS
Eastside Division	Support of San Joaquin River requirements and objectives at Vernalis	Vernalis flow requirements February to June, Vernalis water quality objectives	SWRCB
New Melones Dam & Reservoir Operations	Flows for fish & wildlife; dissolved oxygen standards at Ripon	Release a minimum of 98,000 acre-feet of water to lower Stanislaus River below Goodwin Dam	SWRCB & DFG

[5] Provides flexibility to temporarily allow intermittent gate closures (up to 10 days, one time per year) to be approved on a case-by-case basis to meet critical diversion needs. Reclamation will reopen the gates for a minimum of 5 consecutive days, prior to June 15 of the same year in a manner that will be least likely to adversely affect water deliveries.

[6] While commercial navigation no longer occurs between Sacramento and Chico Landing, long-term water users diverting from the river have set their pump intakes just below a minimum flow requirement of 5,000 cfs at Wilkins Slough. Diverters are able to operate for extended periods at flows as low as 4,000 cfs at Wilkins Slough; pumping operations become severely affected and some pumps become inoperable at flow less than 4,000 cfs. While no criteria have been established for critically dry years, the standard can be relaxed to a minimum flow of 3,500 cfs for short periods to conserve water storage in Shasta Reservoir and manage for multiple project and environmental objectives.

Table B-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Delta Cross Channel	Gate Closures	Gates closed February through May, 14 days May 21 to June 15, 45 days November 1 to January 1 to protect Sacramento River salmonids	SWRCB
Tracy & Banks Pumping Plants	Pumping Curtailments	Protect listed salmonids; meet export/Inflow ratio, X2, delta outflow requirements	SWRCB; NMFS
Contra Costa Canal operations	Diversion rate limits, fish screens	Protect listed salmonids	NMFS
Ocean Salmon Harvest	All California ocean commercial and sport salmon fisheries are currently managed by PFMC harvest regulations	Conservation Objective = 122,000 to 180,000 natural and hatchery Sacramento River Fall Run Chinook (SRFC) salmon spawners[7] Ocean commercial and recreational harvest in the ocean was banned in 2008 and 2009	NMFS, California Fish and Game Commission, Pacific Fishery Management Council
Inland Salmon Harvest	Zero bag limit on the American River, Auburn Ravine Creek, Bear River, Coon Creek, Dry Creek, Feather River, Merced River, Mokelumne River, Napa River, San Joaquin River, Stanislaus River, Tuolumne River, Yuba River, and the Sacramento River except for a one salmon bag limit in the Sacramento River from Red Bluff Diversion Dam to Knights Landing from November 1 to December 31.	To protect fall-run Chinook salmon stocks starting in 2008	California Fish and Game Commission

[7] The conservation objective has been set by the Pacific Fishery Management Council in the Salmon Fishery Management Plan.

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Attachment C

Sacramento River Flows at Red Bluff Diversion Dam and Freeport

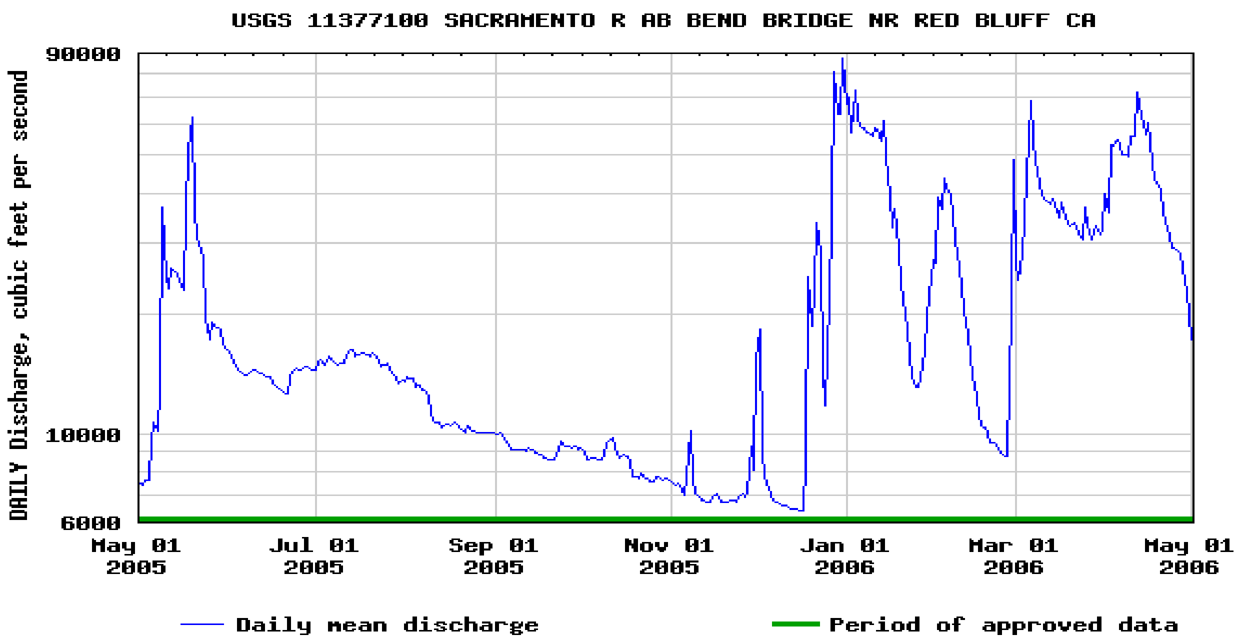

Figure C-1. Daily flows on the Sacramento River at Red Bluff Diversion Dam from May 1, 2005-May 1, 2006(Source: USGS).

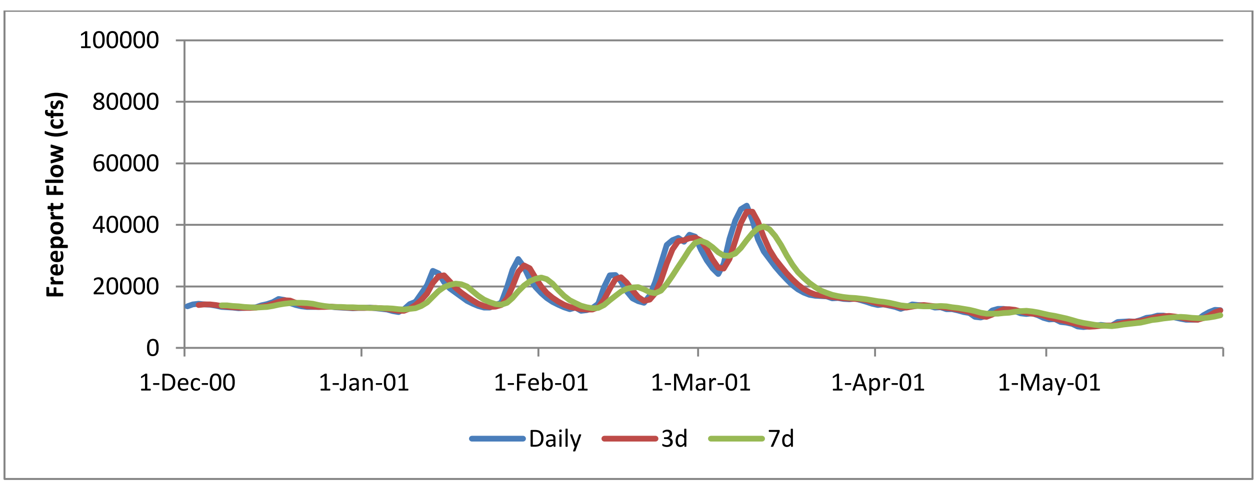

Figure C-2. Daily flow in the Sacramento River at Freeport - 2001(Source: DWR DAYFLOW).

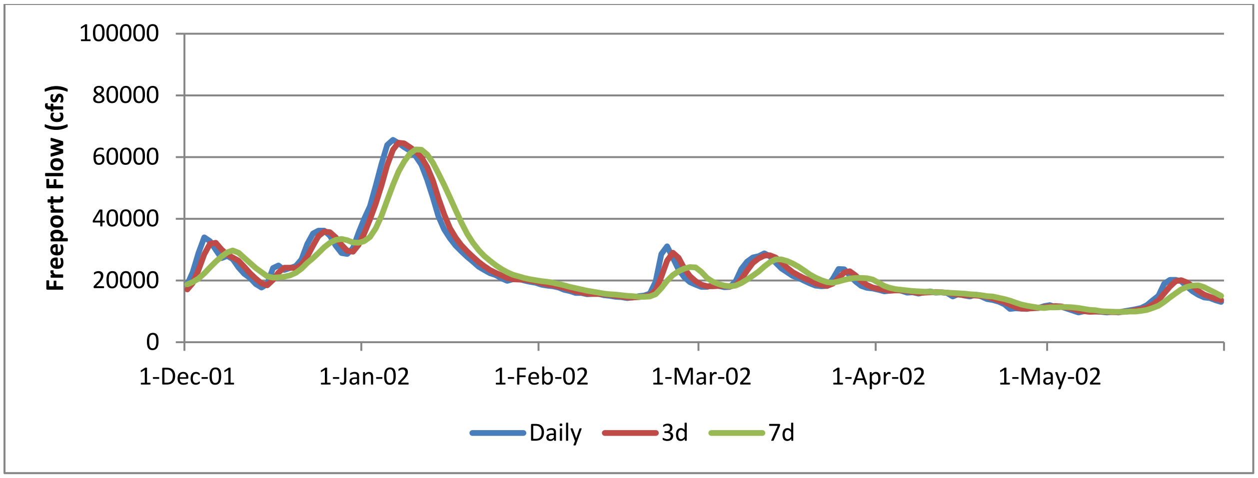

Figure C-3. **Daily flow in the Sacramento River at Freeport – 2002 (Source: DWR DAYFLOW).**

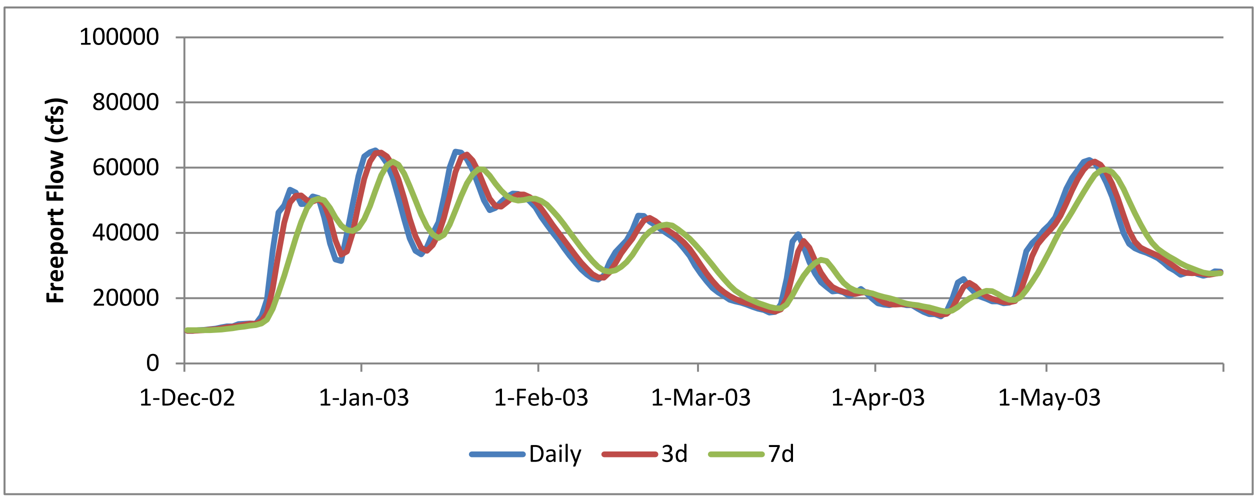

Figure C-4. **Daily flow in the Sacramento River at Freeport – 2003 (Source: DWR DAYFLOW).**

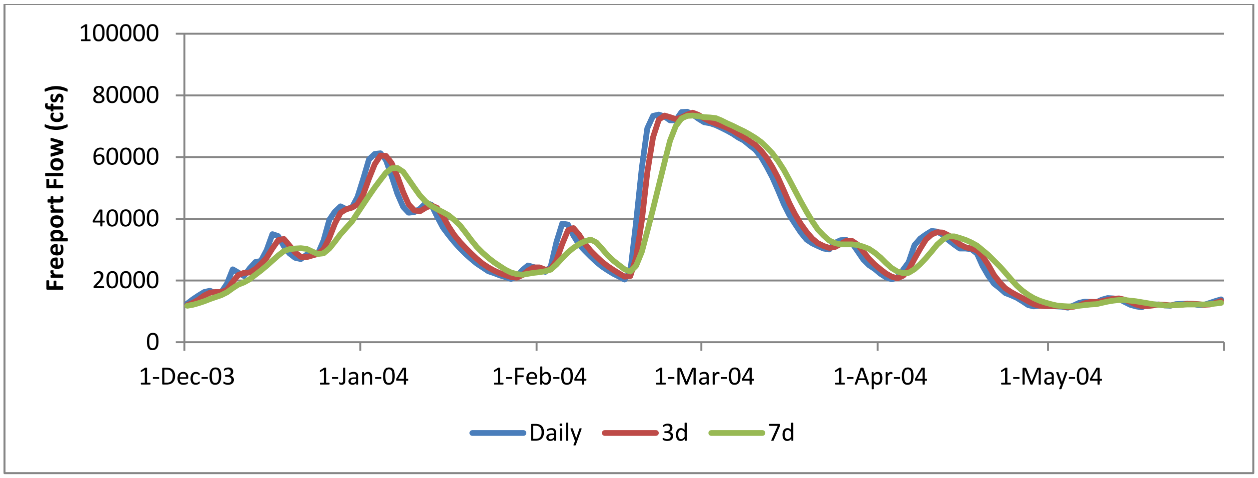

Figure C-5. Daily flow in the Sacramento River at Freeport – 2004 (Source: DWR DAYFLOW).

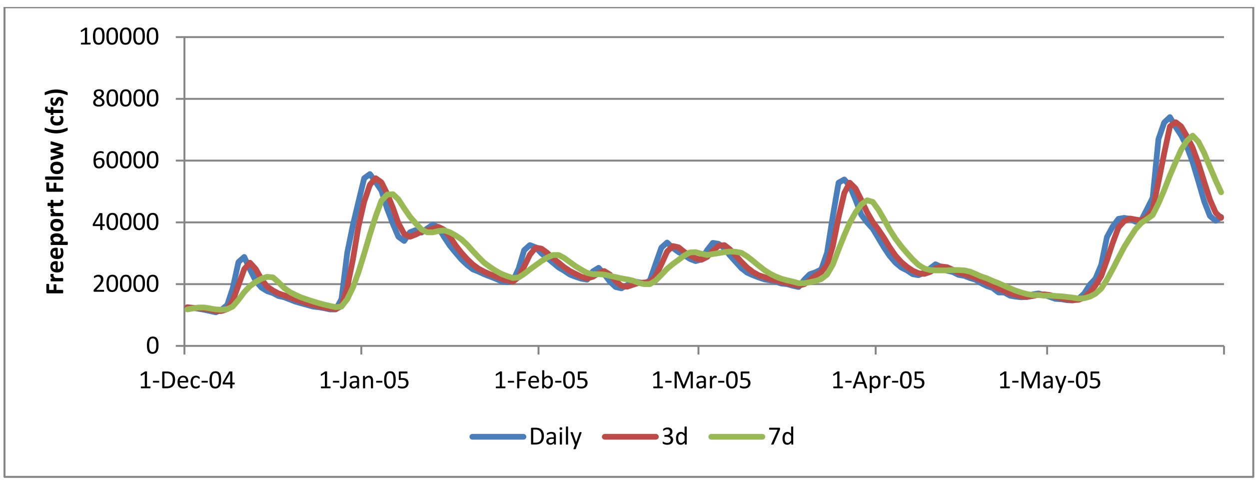

Figure C-6. Daily flow in the Sacramento River at Freeport - 2005 (Source: DWR DAYFLOW).

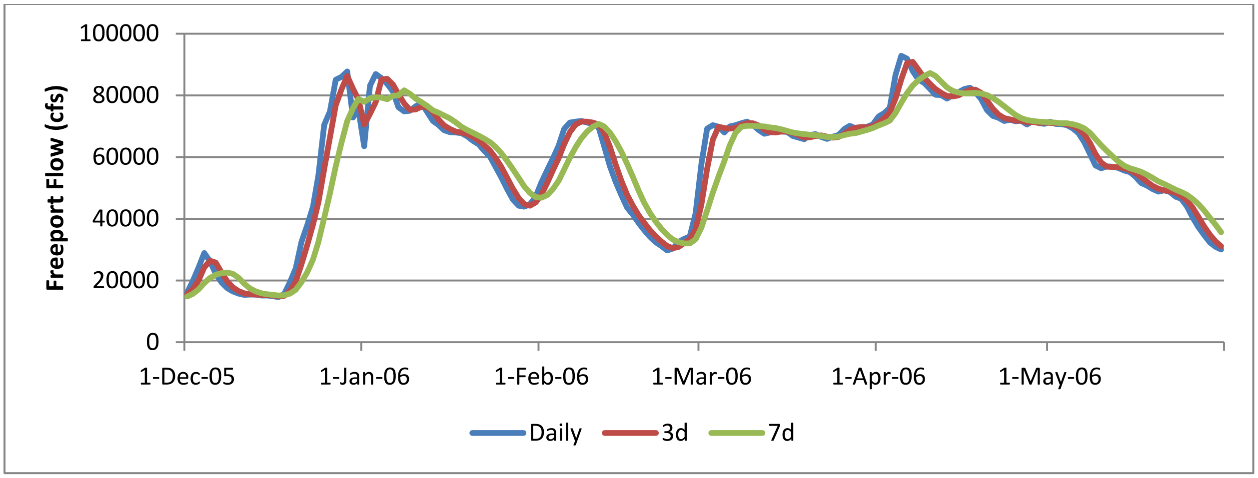

Figure C-7. Daily flow in the Sacramento River at Freeport - 2006 (Source: DWR DAYFLOW).

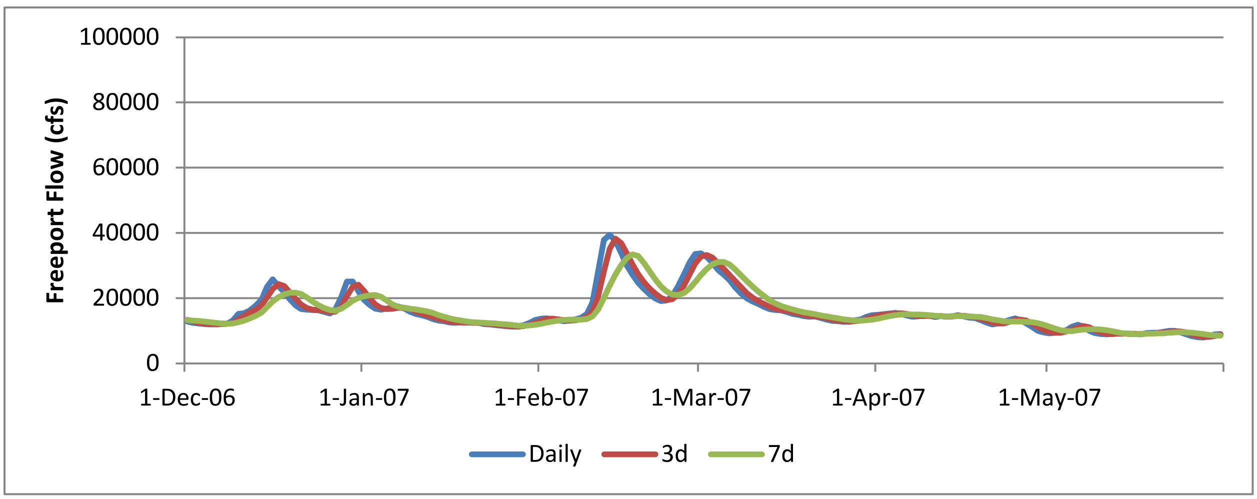

Figure C-8. Daily flow in the Sacramento River at Freeport - 2007 (Source: DWR DAYFLOW).

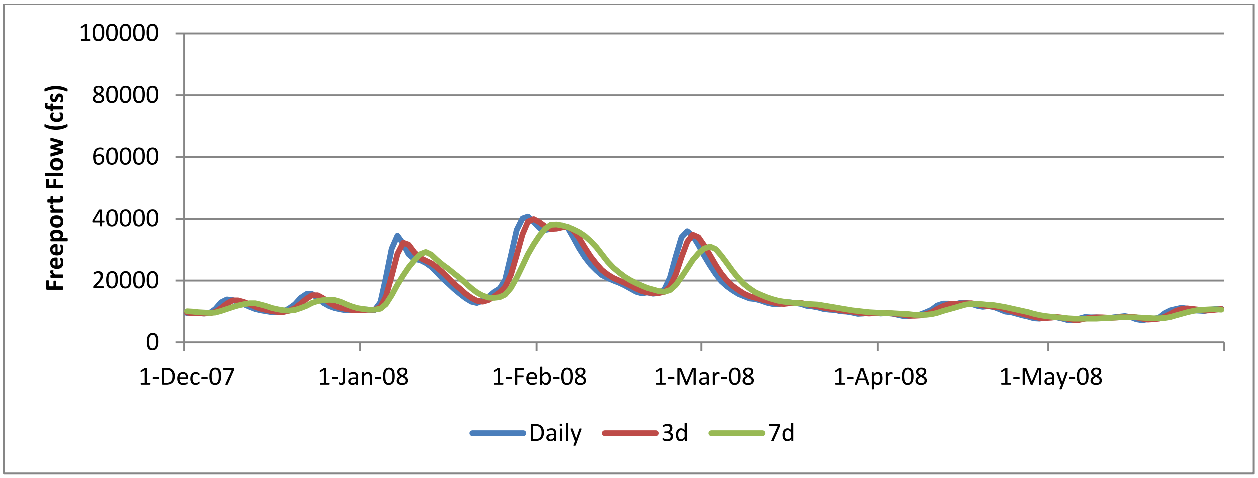

Figure C-9. Daily flow in the Sacramento River at Freeport - 2008 (Source: DWR DAYFLOW).

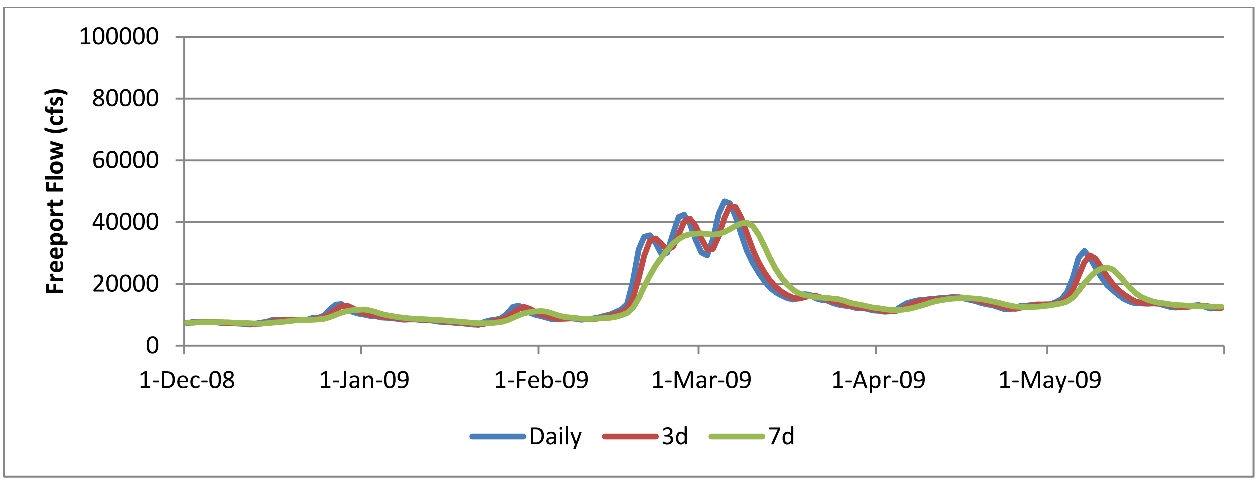

Figure C-10. Daily flow in the Sacramento River at Freeport - 2009 (Source: DWR DAYFLOW).

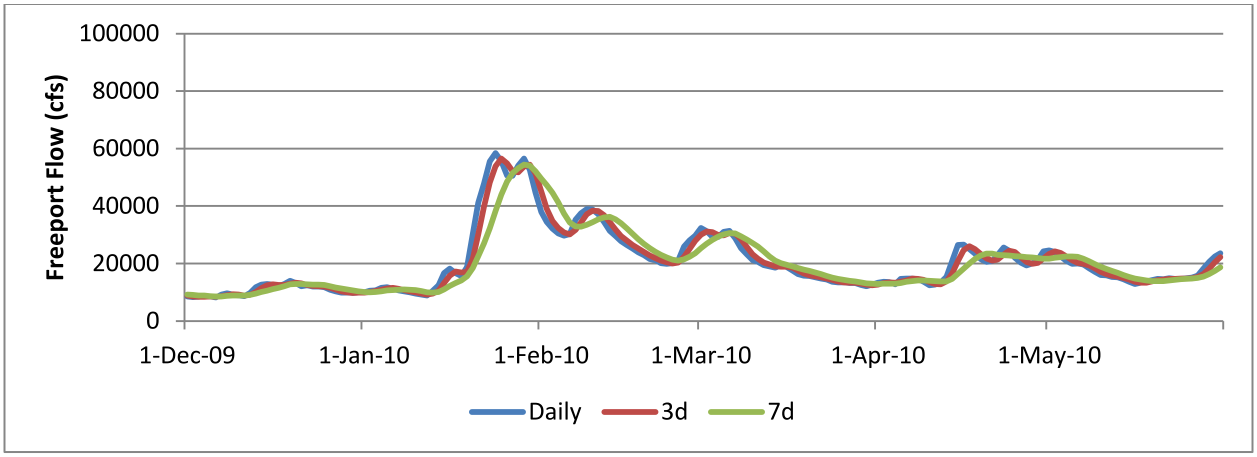

Figure C-11. Daily flow in the Sacramento River at Freeport - 2010 (Source: DWR DAYFLOW).

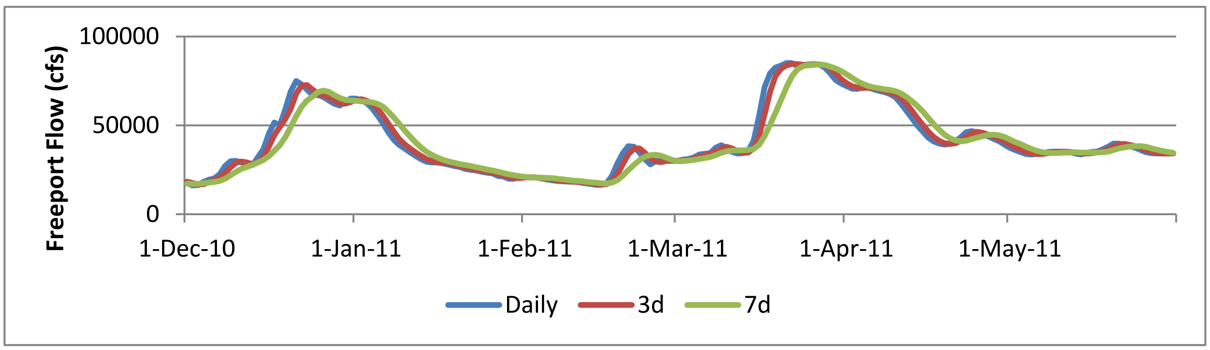

Figure C-12. Daily flow in the Sacramento River at Freeport - 2011 (Source: DWR DAYFLOW).

Electronic file name	Title of paper
adams_et_al_2002.pdf	Satus review for North American greem sturgeion
alpine_cloern_1992.pdf	Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary
ambler_et_al_1985.pdf	Seasonal cycles of zooplankton from San Francisco Bay
baxter_dfg_1999.pdf	Osmeridae in: Report on the 1980-1995 Fish, Shrimp, and Crab Sampling in the San Francisco Estuary, California
baxter_etal_2009.pdf	Effects Analysis State Water Project Effects on Longfin Smelt
baxter_etal_iep_2010.pdf	Interagency Ecological Program 2010 Pelagic Organism Decline Work Plan and Synthesis of Results
bdcp_2012.pdf	Bay-Delta Conservation Plan. 2012. Conservation strategy (Sections 3.4 and 3.5). Administrative draft.
beamesderf_etal_2004.pdf	Historical and current information on green sturgeon occurrence in the Sacramento and San Joaquin rivers and tributaries.
beamesderf_etal_2007.pdf	Use of life history information in a population model for Sacramento green sturgeon.
becker_1991.pdf	Recommended guidelines for measuring conventional marine water-column variables in Puget Sound
beggel_etal_2010.pdf	Sublethal toxicity of commercial insecticide formulations and their active ingredients to larval fathead minnow (Pimephales promelas)
bennett_etal_2002.pdf	Plasticity in vertical migratin by native exotic estuarine fishes
bennett_2005.pdf	Critical assessment of the delta smelt population in the San Francisco estuary, California
bennett_etal_2008.pdf	Interplay of environmental forcing and growth-selective mortality in the poor year-class success of delta smelt in 2005. Final report: Fish otolith and condition study 2005
bennett_moyle_1996.pdf	Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Delta. In Hollibaugh JT (ed.) San Francisco Bay: The Ecosystem. Pacific Division of the American Association for the Advancement of Science
bennett_sfei_1998.pdf	Silversides, smelt, and the slough of dreams: Who will come if we restore it?
berg_etal_2001	Variability in inorganic and organic nitrogen uptake associated with riverine nutrient input
boehloert_morgan_1985	Tubbidity enhances feeding abilityies of larval Pacific herring
brooks_etal_2012.pdf	Life histories, salinity zones, and sublethal contributions of contaminants to pelagic fish declines illustrated with a case study of San Francisco Estuary, California, USA
brown_iep_2009.pdf	Phytoplankton community composition: The rise of the flagellates
brown_sfews_2003.pdf	Will tidal wetland restoration enhance populations of native fishes?
brown_et_al_2012.pdf	Draft synthesis of studies in the fall low salinity zone of SF estuary
brown_et_al_1996.pdf	An evalation of the effectiveness of fish salvage operation at the intake
cdfg_2008	A status review of the threatened delta smelt (Hypomesus transpacificus) in California. Report to California Fish and Game Commission
cappiella_etal_1999.pdf	Sedimentation and bathymetry changes in Suisun Bay: 1867-1990
carlton_etal_1990.pdf	Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam Potamocorbula amurensis
caro_etal_2005.pdf	Use of substitute species in conservation biology
caro_2010.pdf	Conservation by proxy
cavallo_etal_2011.pdf	Use of real-time quantitative polymerase chain reaction to detect delta smelt DNA in the stomach contents of predators
chigbu_etal_1998.pdf	Abundance and distribution of Neomysis mercedis and a major predator, longfin smelt (Spirinchus thaleichthys) in LakeWashington. Hydrobioilogia
cloern_1987.pdf	Turbidity as a control on phytoplankton biomass and productivity in estuaries
cloern_2007.pdf	Habitat connectivity and ecosystem productivity: Implications from a simple model
cloern_etal_2011.pdf	Projected evolution of California’s San Francisco Bay-Delta river system in a century of climate change
contreras_dfg_2011.pdf	Summer Townet Survey Delta Smelt Index. Memorandum
dale_beyeler_2001.pdf	Challenges in the development and use of ecological indicators
dege_brown_afs_2004.pdf	Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco estuary
deri_etal_2010.pdf	Measuring the short-term success of grassland restoration: The use of habitat affinity indices in ecological restoration
deriso_2011.pdf	Declaration of Dr. Richard B. Deriso in support of Plantiffs' motion for injunctive relief dated 01/28/2011. Delta smelt consolidated cases 1:09-cv-00407-OWW-DLB, document 772
dugdale_etal_2007.pdf	The role of ammonium and nitrate in spring bloom development in San Francisco Bay
dunham_etal_2003.pdf	Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range
Duke_etal_1999	Journal of Applied Ichthyology
feyrer_etal_2003.pdf	Dietary shifts in a stressed fish assemblage: Consequences of a bivalve invasion in the San Francisco Estuary
feyrer_etal_2011.pdf	Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish
feyrer_etalcjfas2007.pdf	Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco estuary
feyrer_etaltafs_2007.pdf	Living in a dynamic environment: Variability in life history traits of age-0 splittail in tributaries of San Francisco Bay
feyrer_etaltafs2007.pdf	Otolith Microchemistry Provides Information Complementary to Microsatellite DNA for a Migratory Fish
foott_etal_2006.pdf	Histological evaluation and viral survey of juvenile longfin smelt (Spirinchus thaleichthys) and threadfin shad (Dorosoma petenense) collected from the Sacramento-San Joaquin River Delta, April-November 2006
foott_stone_2008.pdf	Histological evaluation and viral survey of juvenile longfin smelt (Spirinchus thaleichthys) and threadfin shad (Dorosoma petenense) collected from the Sacramento-San Joaquin River Delta, April-November 2007
ganju_etal_2009.pdf	Hindcasting of decadal-timescale estuarine bathymetric change with a tidal-timescale model
ganju_etal_2011.pdf	Discontinuous hindcast simulations of estuarine bathymetric change: A case study from Suisun Bay, California
glibert_2010.pdf	Long-term changes in nutrient loading and stoichiometry and their relationships with changes in the food web and dominant pelagic fish species in the San Francisco estuary, California
glibert_2012.pdf	Ecological stoichiometry and its implications for aquatic ecosystem sustainability
glibert_etal_2004.pdf	Evidence for dissolved organic nitrogen and phosphorous uptake during a cyanobacterial bloom in Florida bay
glibert_etal_2006.pdf	Escalating worldwide use of urea – a global change contributing to coastal eutrophication
glibert_etal_2011.pdf	Ecological stoichiometry, biogeochemical cycling, invasive species and aquatic food webs: San Francisco estuary and comparative systems
gray_etal_prep_2012.pdf	Range and Frequency of Occurrence for Longfin Smelt Spirinchus thaleichthys in the San Francisco Estuary (will provide once submitted)
gould _kimmerer_2010.pdf	Development, growth, and reproduction of the cyclopoid copepod Limnoithona tetraspina in the upper San Francisco Estuary
greene_etal_2011.pdf	Grazing impact of the invasive clam Corbula amurensis on the microplankton assemblage of the northern San Francisco Estuary
grimaldo_etal_2009.pdf	Dietary Segregation of Pelagic and Littoral Fish Assemblages in a Highly Modified Tidal Freshwater Estuary
hamilton_murphy.pdf	In prep. Habitat affinity analysis as a tool to guide environmental restoration for an imperiled estuarine fish: the case of the delta smelt in the Sacramento-San Joaquin Delta (will provide a copy when finalized)
hieb _fleming_1999.pdf	Report on the 1980-1995 fish, shrimp and crab sampling in the San Francisco Estuary, California
hobbs_etal_2010.pdf	The use of otolith strontium isotopes (87Sr/86Sr) to identify nursery habitat for a threatened estuarine fish

Electronic file name	Title of paper
huggett_et_al_2010.pdf	A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay–Delta
hunsaker_et_al_1990	Ecological indicators for regional monitoring
jaffe_et_al_1998.pdf	Sedimentation and bathymetric change in San Pablo Bay: 1856-1983. USGS open-file report 98-759
jassby_etal_1995.pdf	Temperature trends at several sites in the upper San Francisco Estuary
jassby_etal_2002.pdf	Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem
jassby_2008.pdf	Temperature trends at several sites in the upper San Francisco Estuary
kimmerer_2002.pdf	Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages?
kimmerer_2004.pdf	Open water processes of the San Francisco Estuary: From physical forcing to biological responses
kimmerer_etal_cjfas_2000.pdf	Analysis of an estuarine striped bass (Morone saxatilis) population: influence of density dependent mortality between metamorphosis and recruitment
kimmerer_etal_ec_2009.pdf	Is the Response of Estuarine Nekton to Freshwater Flow in the San Francisco Estuary Explained by Variation in Habitat Volume?
kimmerer_etal_meps_1994.pdf	Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay
kimmerer_meps_2006.pdf	Response of anchovies dampens effects of the invasive bivalve Corbula amurensis on the San Francisco Estuary foodweb
kucas_usfws_1986.pdf	Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) - northern anchovy
lam_etal_2008.pdf	Modeling seasonal distribution of pelagic marine fishes and squids. In Cheung et al.
landres_etal_1988.pdf	Ecological uses of vertebrate indicator species: a critique
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