Delta Outflows and Related Stressors Workshop

February 10 and 11, 2014

PWA Supporting Documentation

DELTA SMELT, LONGFIN, AND SALMON

Field, laboratory, and data analyses to investigate the distribution and abundance of Longfin Smelt in the San-Francisco Estuary

Final Study Plan
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Background

The State Water Contractors (SWC), the California Department of Fish and Wildlife (CDFW), and collaborators have identified a suite of studies that would expand our current understanding of Longfin Smelt distribution, abundance, abundance trends, spawning location(s), and the relationship between Delta outflow and Longfin Smelt abundance (e.g. Kimmerer 2002).

This document serves as an overview of the range of proposed studies to be conducted by UC Davis researchers and other contractors to address new observations and data analyses regarding the population biology of Longfin Smelt in the San Francisco Estuary, and how it may pertain to current management of the species. A conceptual model for our current understanding of Longfin Smelt biology and life cycle in the San Francisco Estuary is presented. As a result of recent observations and data analyses pertaining to the conceptual model, eight study questions were derived to further explore these new observations. This study plan describes the approach for addressing each of these 8 study questions during an initial pilot year of research. After initial pilot field studies and analyses are conducted, the study questions will be refined with newly gained knowledge. Field research is planned for 6 of the 8 study questions for up to five years, while follow-up field research to address the final two study questions may be conducted if deemed worthwhile by the Longfin Smelt Technical Team (described below), and if the studies are feasible given resources of the Interagency Ecological Program (IEP). The array of study elements included in these investigations may increase or be refined based on subsequent collaborative discussions with various experts. Towards that end, we propose the formation of a new IEP Project Work Team (PWT) to help guide the study in coordination with the Longfin Smelt Technical Team. The IEP PWT will provide a collaborative basis for reviewing and obtaining feedback from the broader scientific community about study plans and results of analyses from these and other investigations, and assist in identifying further areas of investigation and refining the study design of this research in future years. The Longfin Smelt Technical Team will work collaboratively with the IEP PWT to determine project direction and implement and coordinate the suite of studies. As additional necessary investigations are identified (e.g., for the final two study questions posed in this study plan), detailed study plans (*e.g.*, experimental design, specific methods, staffing, resource needs, logistics and coordination with other studies and CDFW monitoring activities) will be distributed for IEP review.

Problem statement

Two IEP surveys identify different Longfin Smelt distribution and abundance patterns based on different sampling methods. Since the mid-1980s, data from the Fall Midwater Trawl (FMWT, which samples the upper 35-40 ft of the water column) suggest severe declines in species abundance (MacNally et al. 2010), while data from the San Francisco Bay Study otter trawl (which only samples the bottom meter of the water column) suggest only moderate declines in species abundance. With respect to distribution, the FMWT data since the mid-1980s indicates that the population geographic distribution is much more heavily weighted toward Suisun Bay and the Delta while the otter trawl indicates that the Longfin Smelt population is more centralized in the San Francisco Bay below Carquinez Strait (Rosenfield and Baxter 2007; CDFW unpublished data). The ability of the FMWT and otter trawl surveys to accurately characterize species density and distribution may be influenced by several factors, including environmental variables such as turbidity, survey station depth, and the behavior of the fish (e.g., diel movements of Longfin Smelt).

Furthermore, preliminary results from exploratory surveys conducted as part of other monitoring programs have shown evidence that Longfin Smelt use tributaries to northern, central, and south Bay as spawning habitat; however, the frequency (e.g. wet vs dry years) and magnitude of the contribution of tributary spawning to adult abundance and year class strength is currently unknown, as these areas are not included in routine monitoring work. Evidence of successful spawning by Longfin Smelt has been reported as part of expanded 20 mm smelt surveys in the lower Napa River as well as observations of pre-spawning adult Longfin Smelt associated with South Bay Salt Pond restoration monitoring (Hobbs *et al*. 2012). Moreover, Longfin Smelt likely use ocean habitat for rearing during a portion of their life cycle (Rosenfield and Baxter (2007), but the timing and magnitude of offshore use is very poorly understood.

As recently described by Cowin and Bonham (2013), a more complete understanding of the geographic extent of the population at each life stage and how various factors may influence monitoring results is needed to inform more effective management and protection of the species, including habitat restoration and water project operations. In a broad context, this understanding is critically important to management for activities under the Ecosystem Restoration Program, and design and implementation of the Bay Delta Conservation Plan.

In this study plan, we develop a series of special studies, designed to enhance our understanding of (a) distribution of Longfin Smelt reproduction and relative contribution of geographic areas used for spawning to overall abundance; (b) the influence of environmental factors, such as hydrology, on the distribution of reproduction; and (c) the influence of time of day, water transparency, or tidal fluctuation on catch of Longfin Smelt in various IEP surveys.

Objectives

The overarching goal of this new set of proposed Longfin Smelt studies is to provide additional information about Longfin Smelt that is expected to improve management and protection of this species in the San Francisco Estuary. Generally, these studies aim to enhance our knowledge of the life history and ecology of Longfin Smelt and to refine our understanding of the drivers of population distribution, and abundance, including the relationship between freshwater outflow and the abundance of Longfin Smelt. We separate our specific study objectives into two broad categories: (1) Longfin Smelt distribution and regional contribution to overall abundance; and (2) Longfin Smelt vertical migration behavior.

The first general goal (detailed by Objectives 1 – 4, below) is to investigate Longfin Smelt distribution and quantify the relative contribution of geographic areas used for spawning to overall population abundance. Since most Bay tributaries are not sampled by current long-term surveys, a key question is to determine if Longfin Smelt spawn and recruit in Bay tributaries; and if so, whether they do so in appreciable numbers to have an effect on overall species abundance. Sampling of tributaries to San Francisco and San Pablo Bays (Bay tributaries) not previously monitored by IEP-DFW for adult and larval stages of Longfin Smelt will thus enhance our knowledge of the distribution of the species. Furthermore, analysis of otolith geochemical signatures from Bay tributary fish and fish collected by DFW abundance index surveys will provide for an assessment of the contribution of different geographical areas and salinity zones to the recruited juvenile and adult populations. Conducting this research during both wet and dry years will allow us to understand how freshwater inflow into and outflow from the estuary and its tributaries may influence tributary use and the contribution of Bay tributary spawning to the population abundance index.

In addition to improving our understanding of Longfin Smelt distribution in the Estuary, a second overall objective of this work (detailed in Objectives #5-7) is to evaluate movements of Longfin Smelt in the water column with respect to changes in environmental conditions (e.g. diel and tidal cycles, turbidity, seasons, regions). Conducting research on the effects of environmental conditions (e.g., diel and tidal variation, turbidity, seasonal changes) should improve our understanding and interpretation of monitoring survey results from the FMWT and Bay Study.

Specifically, the proposed study's primary objectives are as follows:

Longfin Smelt distribution and regional contribution to overall abundance:

1. Quantify the relative abundance of early life stages and adult Longfin Smelt in Bay tributaries (e.g. Napa River, Sonoma Creek, Petaluma River, Alameda Creek and Coyote Creek) during the spawning and rearing seasons occurring during wet and dry years.

2. Determine if geochemical signatures of Bay tributaries vary to the extent that otolith geochemistry could be used to determine the relative contribution of Bay tributaries to recruited juvenile and adult fish collected in IEP-DFW surveys in the San Francisco Bay.

3. Determine the extent to which initial rearing in different salinity zones and geographic areas contribute to the Longfin Smelt population and compare these contributions between wet and dry years.

4. Determine if geochemical signatures of the ocean environment can inform the extent to which Longfin Smelt use the near-shore ocean environment using otolith geochemical signatures.

Longfin Smelt vertical migration behavior

5. Determine the extent to which Longfin Smelt exhibit regular vertical movements within the water column during the day-night cycle, and whether these behaviors vary among different regions of the estuary or seasonally.

6. Determine the relationship between water transparency and the Longfin Smelt catch in the Bay Study MWT and otter trawl surveys.

7. Determine whether changes may be needed in current Longfin Smelt survey index calculation methods, and whether the new information provides better insight into the proper formulation of quantitative population estimates.

Conceptual model

The current conceptual model of the Longfin Smelt basic population biology and potential factors associated with their decline in abundance is presented in Figure A. A much more detailed conceptual model is available in Rosenfield (2010). Key aspects of the life history relevant to the proposed investigation are described below along with new analyses of existing data and new surveys being conducted by DFW and UCD.

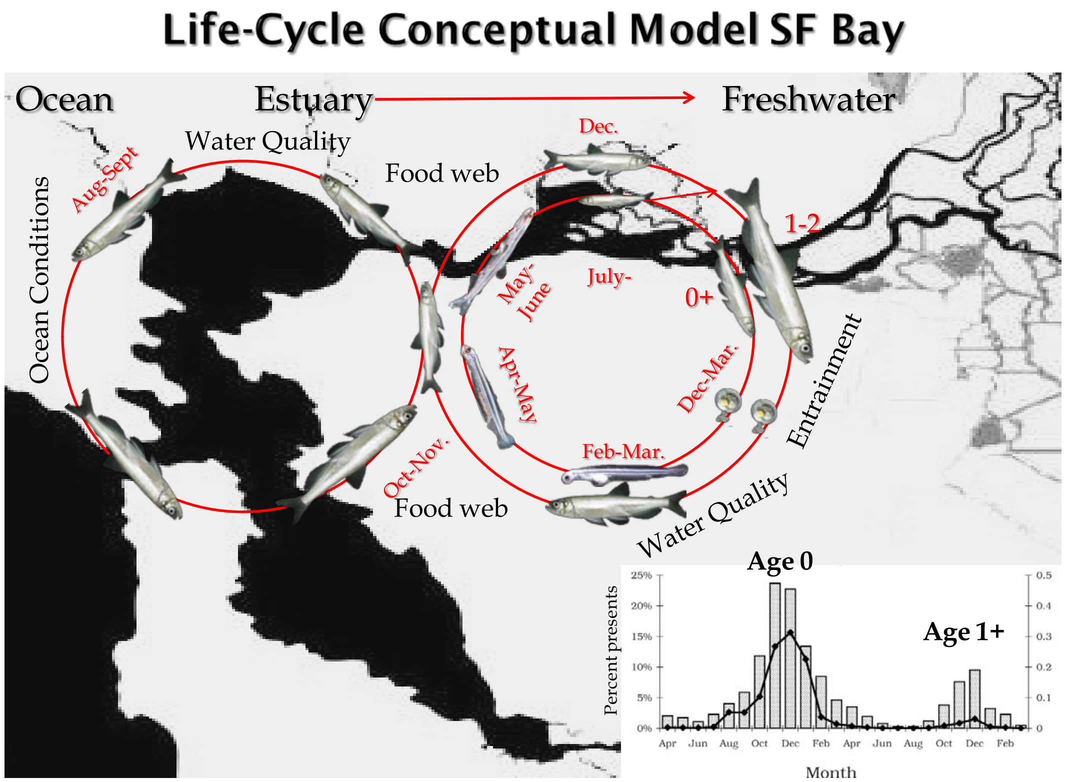

Figure A. Life cycle conceptual model of SF Bay with spawning only occurring in Suisun Bay and the Delta.

<u>*General life-cycle*</u>

Longfin Smelt have been found to utilize a variety of habitats including, freshwater, low-salinity, brackish and near shore ocean habitats throughout their 2-3 year life-cycle. Larvae occur in freshwater to brackish habitats, whereas juveniles and sub-adults can be found throughout San Francisco Bay including nearshore marine areas with salinities greater than 30-ppt. It appears that juvenile and adult Longfin Smelt are sensitive to warmer water conditions in the late summer-early fall, either residing in deep, cool, bay channel habitats or, marine habitats, potentially outside San Francisco Bay in the fall (Rosenfield and Baxter 2007). There also appears to be a movement to the ocean during the second summer (1+ year olds) of life; however, the frequency and magnitude of the contribution of ocean rearing or ocean conditions to the adult population is unknown. Our current knowledge regarding spawning habitat is based on observations of increased catch in DFW surveys and a spawning run of adults observed in the Delta near the confluence of the Sacramento and San Joaquin rivers starting around December (Rosenfield and Baxter 2007). Spawning is known to occur in freshwaters upstream of the confluence of the Sacramento and San Joaquin rivers; however, recent evidence suggests that some Longfin Smelt may utilize low-salinity habitats and other Bay tributaries to spawn, particularly during wet years. Significant numbers of Longfin Smelt post-larvae have been observed in the IEP-DFW 20-mm Survey in the Napa River. Moreover, salt pond restoration monitoring in lower South SF Bay has observed a high frequency of occurrence of adult Longfin Smelt and mysid shrimp, that migrate into the restoration area in late fall and remain there during the spawning season, including ripe fish(Hobbs *et al* 2012), (Figure B).

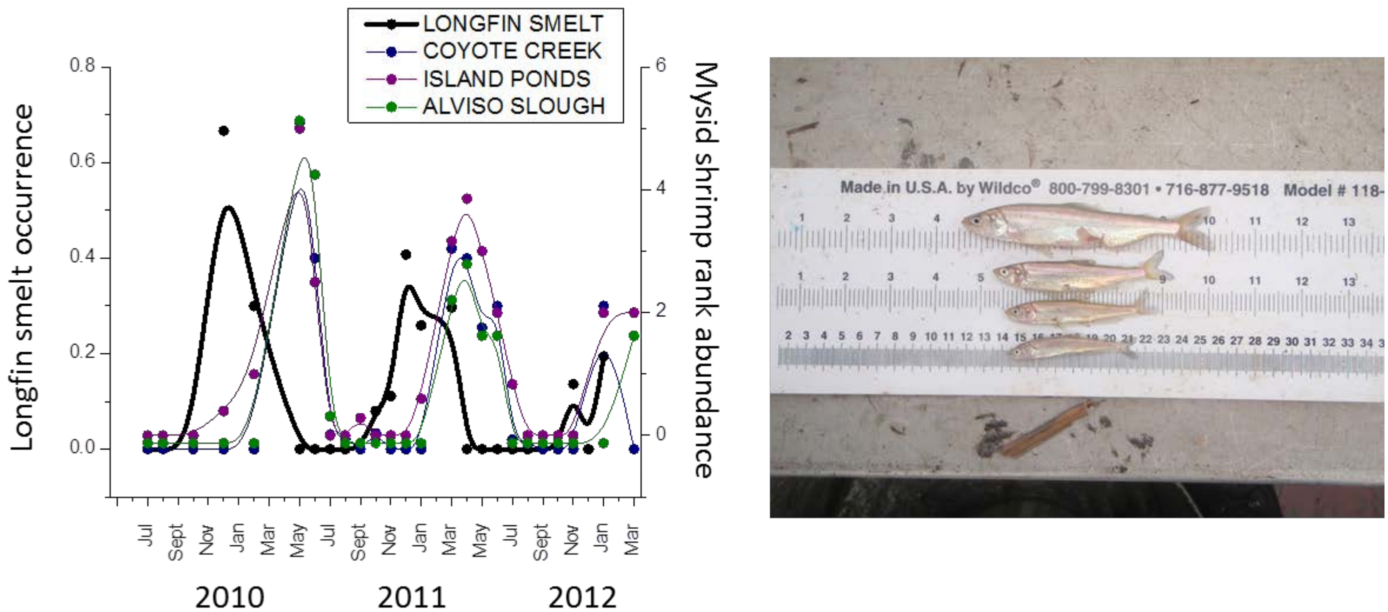

Figure B. Left; Longfin Smelt (black dots and line, frequency of occurrence among 12-15 monthly otter trawls conducted over three years in Lower South Bay) and the ranked abundance of mysid shrimp (colored dots and lines). Right; 3 year classes of Longfin Smelt collected with a restoration pond on Coyote Creek. Note the top fish was in reproductive condition. (*n* = 229 individuals for 42 trawls up through spring of 2012)

<u>Reproductive biology of Longfin Smelt: comparison between Lake Washington and Bay-Delta populations</u>

Longfin Smelt, an important forage fish to larger piscivorous fishes, is distributed from San Francisco Bay to Alaska (Hart 1980). Information on the various aspects of the biology and ecology of the species has been documented based mainly on what is known about the populations in San Francisco Bay (e.g. Kimmerer 2002; Moyle 2002; CDFG 2009; see also review by Robinson and Greenfield 2011) and Lake Washington (Moulton 1970,1974; Dryfoos 1965; Traynor, 1973; Chigbu and Sibley 1994a,b, 1998a,b; Chigbu *et al*. 1998, Sibley and Chigbu 1994). Nevertheless, the two systems are different: the population in San Francisco Bay is anadromous whereas - the Lake Washington population is currently believed to be landlocked, but it connected to Puget Sound historically. This major difference may have important implications with regard to the life history and reproduction of the species.

Lake Washington and the associated tributaries in which Longfin Smelt spawn are freshwater (< 1 ppt) hence, the smelt eggs, larvae, juveniles and adults are not exposed to brackish water conditions. In contrast, smelt in the San Francisco Bay Delta system are believed to spawn in tidal freshwater environments (Robinson and Greenfield 2011). The larval stages are thereafter transported into brackish water areas where they are most abundant at low salinities (≤ 2 ppt), although they have been captured at higher salinities at relatively low numbers (Kimmerer 2002), perhaps because larval mortality increases with increasing salinity (Hobbs *et al*. 2010).

Information is scarce on the reproductive biology of Longfin Smelt, especially in the San Francisco Bay where the migratory and spawning behavior of the adults and characteristics of the microhabitats in which they spawn are unknown. In Lake Washington, Dryfoos (1965) and Moulton (1970, 1974) noted that Longfin Smelt mature and spawn after two years between January and May in tributaries (May Creek, Coal Creek, Juanita Creek, Cedar River) that flow into Lake Washington, although most spawning occurs in the Cedar River, the largest of the tributaries. Few, if any of the Longfin Smelt survive until the following year after spawning. In the San Francisco Estuary, adult Longfin Smelt may migrate short distances upstream into the lower tidal reaches of the Sacramento and San Joaquin rivers during the winter as water temperatures decline below 18 ºC (mature smelt generally migrate upstream during December-February; CDFG 2009) and spawn in the late winter-early spring (December-March). In Lake Washington, spawning migrations and subsequent spawning takes place at night (Moulton 1974). Migration from Lake Washington into rivers and creeks to spawn occurs such that males precede the females in their peak migration times. Temperature during the spawning run of Lake Washington smelt is 5.6 to 6.7 ^{o}C. In San Francisco Estuary it is higher and ranges from 7 – 14.5 ^{o}C (Moyle 2002).

Longfin Smelt eggs are adhesive and tend to attach to the surface of any substrate with which they first come in contact soon after fertilization. In the Lake Washington tributaries, eggs were collected from a variety of substrates, but mostly at sites with some sand and a significant proportion of the eggs were attached to sand grains. A preliminary experiment conducted to evaluate spawning substrate preference in the San Francisco Estuary showed that Longfin Smelt preferred sandy to gravel substrates (Martz *et al*. 1996). Longfin Smelt eggs have not been collected in the Bay-Delta system. The egg development time of Longfin Smelt in Lake Washington varies depending on the temperature, ranging from 25 days (9.6-10.6 ^{o}C, Moulton 1970 to and 40 days at 7 ^{o}C (Dryfoos 1965).

Egg sampling in Lake Washington conducted in the Cedar River (Sibley and Brocksmith 1996; Martz *et al*. 1996) indicated egg presence up to 1200 m upstream from the river mouth, peaking at that 300 - 600 m. No eggs were collected above 1200 m from the river mouth. Water depths at which the highest densities of eggs were found did not exceed 1 m, and the water velocities were less than 0.6 m/s; usually between 0.3 and 0.55 m/s. There are many areas in the San Francisco Bay and its tributaries (e.g. Coyote Creek, Petaluma River, Napa River) with environmental characteristics similar to those in which Longfin Smelt are known to spawn in Lake Washington tributaries, but detailed systematic sampling has not been conducted to determine the extent to which Longfin Smelt utilize such areas to spawn. The Longfin Smelt in the San Francisco Bay may therefore not only be spawning at the boundaries of brackish and fresh water in deeper channels as has been previously hypothesized (see CDFG 2009; Robinson and Greenfield 2011), but may in fact be utilizing shallow brackish and freshwater tributary areas with flow and substrate characteristics similar to those described above for Lake Washington tributaries.

Observations suggesting that Longfin Smelt may also utilize Bay tributaries to spawn and rear include the following: (1) The San Francisco Bay Study (DFW) has observed post-larval stages in South San Francisco Bay during extreme wet years in the 1980s (Baxter *et al*. 1999); observing a length frequency trend that suggested Longfin Smelt successfully spawned in South Bay tributaries with smaller fish being found in lower South Bay (south of the Dumbarton Bridge), near Coyote Creek and larger fish in the mid (between the Dumbarton and San Mateo Bridges) and upper South Bay (north of the San Mateo Bridge) (R. Baxter, unpublished SF Bay Study data). (2) Recent monitoring studies of newly restored shallow salt pond habitats in lower South Bay have detected adult Longfin Smelt during the spawning season, even observing a few ripe individuals (Hobbs *et al* 2012). The relative contribution of Longfin Smelt spawning in these different geographical areas is unknown. However, studies by Hobbs *et al*. (2010) at least suggest that there may be differences in the relative contribution of different salinity zones (e.g. <1 ppt; 1-6 ppt; >6ppt).

The broad distribution of adult Longfin Smelt, further supporting the idea of highly dispersed spawning is illustrated by Merz *et al*., in review, Figure C. These spawning age adult Longfin Smelt are distributed up and down the Bay.

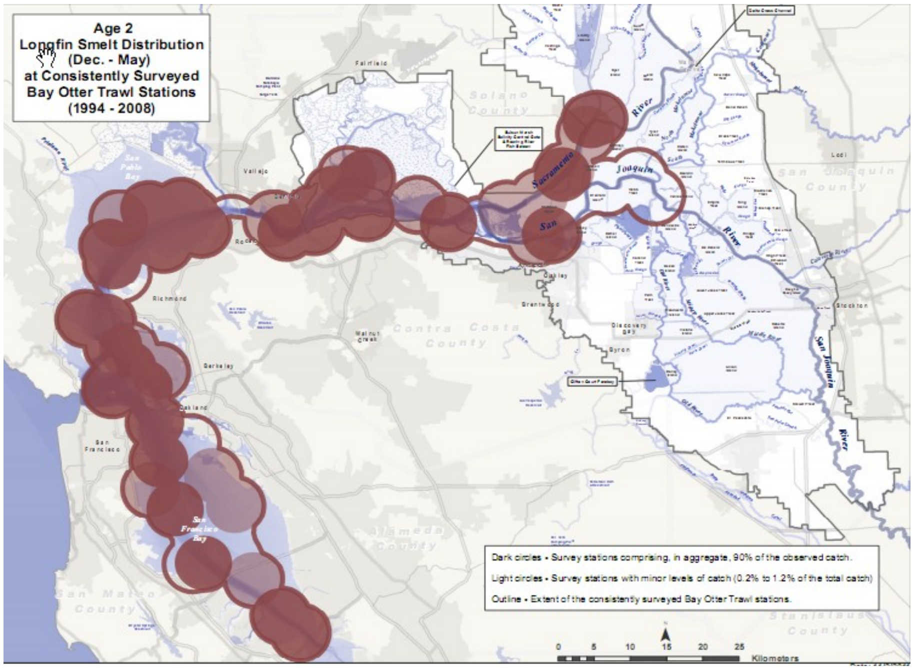

Figure C. Spawning age Longfin Smelt distribution (December-May).

Distribution of Longfin Smelt within the water column.

Longfin Smelt exhibit a daily vertical migration behavior in Lake Washington (Quinn *et al*. 2012; Figure D). Given this evidence from another population, we hypothesize that adult Longfin Smelt in the San Francisco Bay also engage in a daily vertical migration pattern. Evidence for this behavior in the San Francisco estuary has been observed in juvenile Longfin Smelt in Suisun Bay (Bennett el al. 2002); however, this phenomenon has not been investigated in existing IEP survey datasets, nor have directed field studies been carried out for adults.

Spatial and temporal patterns of vertical distribution

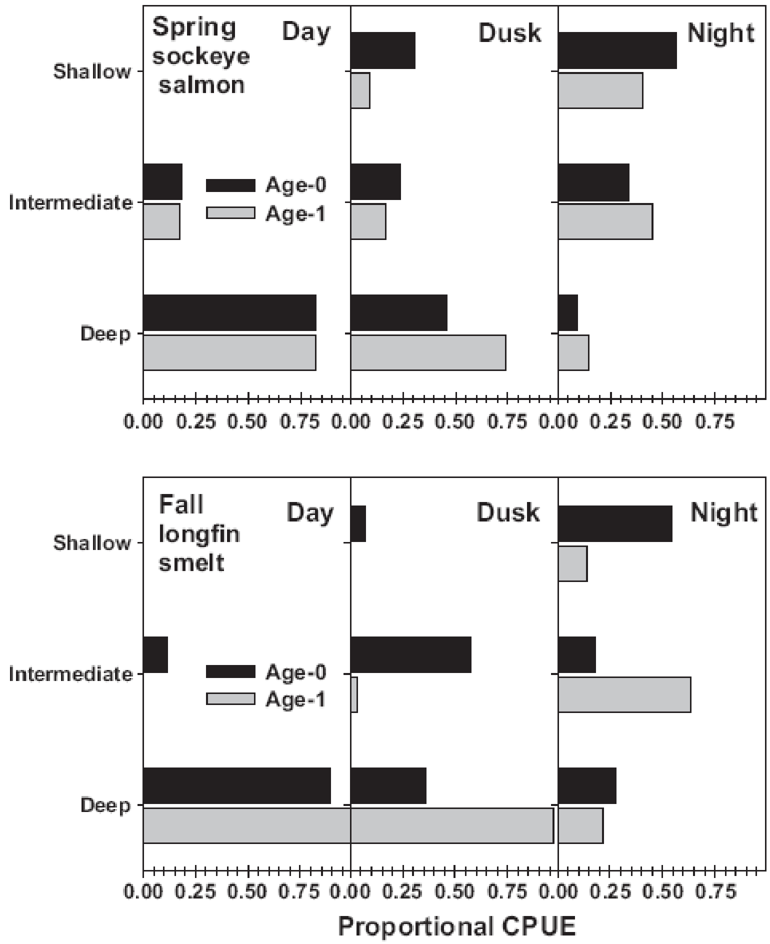

Fig. 3. Diel vertical distributions of age-0 and age-1 sockeye salmon in the spring (top) and longfin smelt in the fall (bottom). Catch-per-unit-effort (CPUE, $N \cdot min^{-1}$) was standardised by the total CPUE for each age class × diel period.

Figure D. Diel vertical distribution of age 0 and age 1 Longfin Smelt (lower panel) in Lake Washington during fall surveys (Source: Figure 3, Quinn *et al*. 2012)

Relationship between Longfin Smelt abundance-Delta Outflow and Salinity

The abundance index of age-0 Longfin Smelt has been found to be positively related to freshwater outflow during the winter to spring period (Kimmerer *et al*., 2002a,b). Therelationship of age-0 Longfin Smelt abundance and outflow has been robust over two different periods in which the abundance of Longfin Smelt sharply declined. The first decline in abundance occurred in 1986 after the introduction of the Asian clam *Potamocorbula amurensis*, and a second decline occurred in the early 2000s, when several pelagic species declined simultaneously and was termed the “pelagic organism decline (POD)” (Sommer *et al*. 2007; Fish *et al*., 2009; Thomson *et al*. 2010) (Figure E). The second step change in abundance was detected in FMWT and Bay Study MWT catch; however, this change was not observed in the Bay Study otter trawl (Figures E, F). The reduction in Longfin Smelt FMWT abundance index after 1987 has been attributed to the reduction in upper estuary productivity — which declined to very low levels by the mid-1990s (Jassby *et al*. 1995, 2002; Kimmerer and Orsi 1996; Orsi and Mecum 1996; Kimmerer 2002). However, the mechanism resulting in the more recent decline in Longfin Smelt production remains to be determined (MacNally *et al*. 2010, Thomson et al. 2010). Several competing hypothesis exist for the decline of Longfin Smelt abundance measured by the FMWT and Bay Study MWT, and are consistent with those proposed for the POD, including reduced food abundance, increased export mortality, predation and poor water quality (Baxter et al 2008). A potential hypothesis for the discrepancy of the FWMT, Bay MWT with the Bay Study otter trawl is that the difference in the Longfin Smelt abundance index trends are the result of changes in the vertical migration behavior associated with increased water clarity

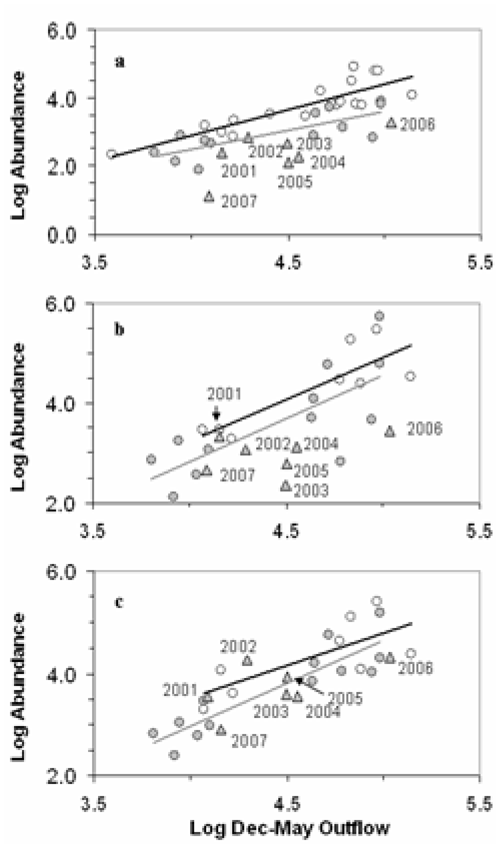

Figure 3. Longfin smelt annual abundance indices plotted on December through May average delta outflow for a) Fall Midwater Trawl (all ages); b) Bay Study Midwater Trawl Age 0; c) Bay Study Otter Trawl Age 0. Relationships depicted are pre-*Corbula amurensis* (1967-1987; open circles, black line) and post-*Corbula amurensis* (1988-2000; filled circles, grey line) and more recent years during the Pelagic Organism Decline (POD) (2001- 2007, grey triangles, no line).

Figure E. Relationships of indices of Longfin Smelt abundance and Delta outflow (Source: Figure 3, Fish *et al*., 2009).

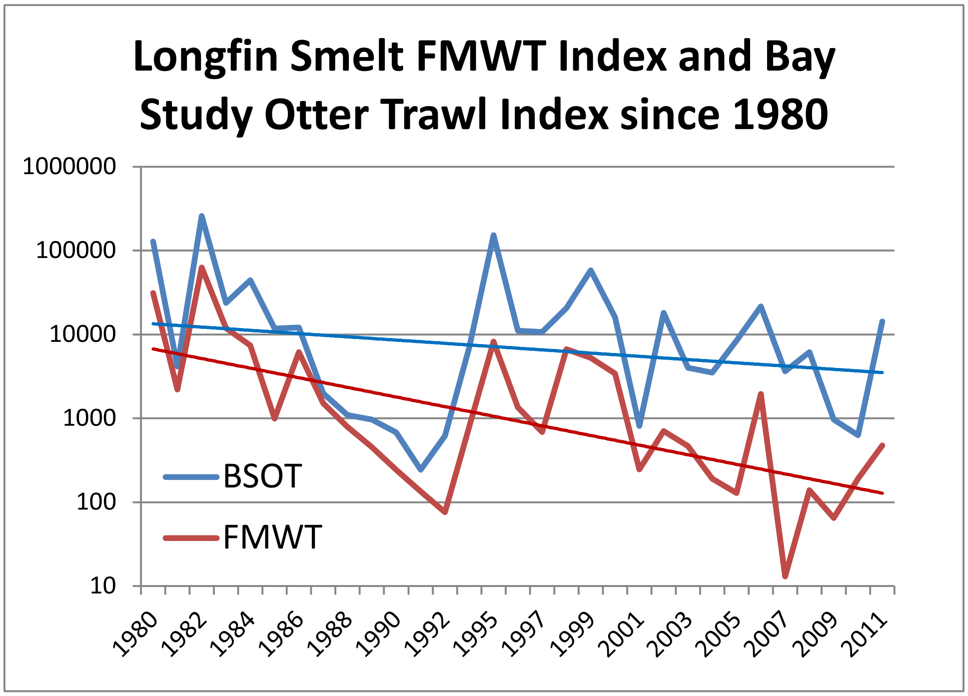

Figure F. Longfin Smelt FMWT Index and Bay Study Otter Trawl Index since 1980. FMWT Index values have declines by nearly two orders of magnitude while Bay Study Otter Trawl values have declined by a little more than 50%.

Gaps in our understanding of the biology of Longfin Smelt

Through our collaborative efforts to better understand the biology of Longfin Smelt and the potential factors associated with decline in abundance, we have advanced our understanding of the species. However we have identified several major data gaps that preclude our ability properly manage the species and assess the different factors associated with the abundance of the fish. The data gaps are primarily associated with recent observations of the spatial distribution of the Longfin Smelt from existing monitoring surveys and new surveys being conducted in habitats not currently sampled by ongoing long-term monitoring programs. The objectives, questions and hypothesis put forth in this study plan are intended to directly address these data gaps, and provide managers with a better understanding of the biology of the species. A second, related, goal is to explore factors that may be associated with the ability of current survey methods to catch Longfin Smelt and thus monitor population trends.

Research Questions and Hypotheses

Longfin Smelt distribution and regional contribution to overall abundance:

1. Do Longfin Smelt spawn in Bay tributaries?

    a. H_o : Longfin Smelt will not be found to spawn in Bay tributaries

    H_a : Longfin Smelt will be found to spawn in Bay tributaries

2. If spawning occurs in Bay tributaries, are there substantial differences in production during wet versus dry years?

    a. H_o : The magnitude of Longfin Smelt production in Bay tributaries does not vary by water year type.

    b. H_a : The magnitude of Longfin Smelt production in Bay tributaries is substantially higher in wet years.

3. Is Longfin Smelt larval production in Bay tributaries sufficient to influence the abundance indices of YOY and adult (age 1+) Longfin Smelt captured by DFW surveys in the estuary? How does the contribution of Bay tributary spawning to year class strength vary in response to variation in hydrologic conditions (e.g., wet vs. dry years, etc.)?

    a. H_o : Larval production in Bay tributaries does not influence the abundance index of YOY and/or adult Longfin Smelt.

    b. H_{a1} : Larval production in Bay tributaries does influence the abundance index of YOY and adult Longfin Smelt.

    c. H_{a2} : The magnitude of tributary spawning and the survival of Longfin Smelt spawned in Bay tributaries (i.e., contribution of tributary spawning to population abundance of juveniles and adults) varies among years in response to hydrologic conditions.

4. Will Bay tributaries have unique geochemical signatures that allow identification of regional geographic areas of production (e.g., differentiate production in Bay tributaries from Sacramento and San Joaquin river production) and, under the best case scenario, have geochemical signatures that would allow differentiation of production among individual tributaries?

a. H_o : Geochemical signatures will not differ among the Sacramento and San Joaquin rivers and Bay tributaries.

b. H_a : Geochemical signatures will be sufficiently different to discriminate between the Sacramento and San Joaquin rivers and Bay tributaries and possibly among individual Bay tributaries.

5. If geochemical signatures are discernible among geographical areas and salinity zones, what is the relative contribution of larvae rearing in different geographical areas and salinity zones to the YOY and adult (age 1+) population?

    a. H_o: Most Longfin Smelt production originates from upstream areas, specifically the low salinity zone of the Sacramento and San Joaquin rivers.

    b. H_a: Bay and Bay tributary production is a major contributor to the Longfin Smelt population.

6. Will geochemical signatures of the Bay differ from the nearshore marine coastal waters such that fish moving into or out of San Francisco Bay could be identified?

    a. H_o : Geochemical signatures of Longfin Smelt in San Francisco Bay will not differ from the nearshore coastal environment.

    b. H_a : Geochemical signatures of Longfin Smelt in San Francisco Bay will be significantly different from the nearshore coastal environment.

Longfin Smelt vertical migration behavior.

7. Do Longfin Smelt undergo a diel (daily) or tidal migration in the water column? If present, does this behavior vary regionally (i.e., in central San Francisco Bay vs. Suisun Bay)?

    a. H_0: Longfin Smelt do not exhibit any diel or tidal vertical migration behavior: catch in the upper part of the water column (as measured by FMWT and Bay MWT) and deeper waters (as measured by the Bay otter trawl) do not vary between night and day, or over tidal cycles.

    b. H_{a1}: Longfin Smelt do exhibit diel or tidal vertical migration behavior: catch in the upper part of the water column (as measured by FMWT and

Bay MWT) and deeper waters (as measured by the Bay otter trawl) varies between night and day, or over tidal cycles, or both.

c. H_{a2}: Longfin Smelt diel or tidal vertical migration behavior varies between regions of the estuary.

8. Is Longfin Smelt catch affected by water transparency?

a. H_0: Water transparency does not influence MWT or otter trawl catch of Longfin Smelt.

b. H_a: Longfin Smelt catch in the upper part of the water column (as measured by FMWT and Bay MWT) and deeper waters (as measured by the Bay otter trawl) varies with water transparency, with decreased catch in the upper water column at high levels of water clarity. This effect of water transparency would result in variation in the catch ratio of BWT:OT across water clarity levels.

Project Approach

Longfin Smelt distribution and regional contribution to overall abundance: (Questions #1 – 6)

This multi-year study would determine if adult and larval Longfin Smelt occur in Bay tributaries and if so, the abundance of Longfin Smelt spawning and successfully rearing in San Francisco Bay tributaries outside of what is thought to be primary spawning grounds at the confluence of the Sacramento and San Joaquin rivers and Delta. The multi-year study design is intended to test hypotheses regarding Bay tributary use by Longfin Smelt between wet and dry years. The specific research questions, study designs and associated hypotheses in this study plan are largely exploratory in nature and thus we anticipate taking an adaptive approach to the overall study, with the first year of the study designed to determine optimal sampling sites for each of the Bay tributaries, compare different gear types (UCD vs. DFW), and investigate the efficacy of otolith geochemistry to distinguish different habitats. and potentially different tributaries. During year one, significant input from the newly formed IEP PWT and Technical Team will be sought to refine study questions and design appropriate approaches and methods, thus the study plan is intended to be flexible in specific question and approaches, yet will seek to address the overarching study objectives.

Year One Study Plan

To get a better understanding of the potential contribution of Bay tributaries to the population, reconnaissance of several Bay tributaries including the Napa River and adjacent restored salt ponds, Sonoma Creek and the Petaluma River in San Pablo Bay; Alameda Creek in South Bay and Coyote Creek in Lower South Bay and adjacent restored salt ponds. Reconnaissance will involve determining specific stations within each Bay tributary, determining safe access points, clearing of debris and other obstructions, mapping of habitat and quantification of available habitat and water volumes for expanding catch for abundance estimates and comparing difference gear types to determine the most effect sampling approach. We will also explore the utility of otolith geochemistry to detect Bay tributary derived fish among the recruited juvenile and adult populations to assess the degree to which Bay tributary spawning contributes to juvenile and adult abundance. Lastly we will expand on the otolith geochemistry approach and investigate the potential to use otolith geochemistry to estimate the proportion of Longfin Smelt that use nearshore ocean environments (rather than staying in the Bay) for the summer-fall period and if adultsindividuals could overwinter in the ocean.

Using our established data on the geochemistry of the Sacramento-San Joaquin Delta and Napa Rivers (Hobbs 2010) and new geochemistry data collected in the initial year of this study, we will determine the degree to which we can reliably distinguish different habitats and tributaries, and determine our ability to quantify Longfin Smelt spawning and rearing in Bay tributaries and address questions regarding Bay tributary contributions to fall and winter indices of adult and juvenile Longfin Smelt abundance. The following tasks and methods are derived from existing experience in sampling shallow Bay tributaries. Again,the study is proposed as a multi-year effort to assess our tools to =determine the contribution of different geographical areas and salinity zones across different water year types to the abundance of recruited juvenile and adult Longfin Smelt. Ideally, these studies would be at least a 5-year effort; however the timeline would depend on future climate conditions, and could potentially be completed in less than 5 years. In the first year, reconnaissance will be conducted to establish specific sampling locations in South Bay tributaries under the environmental conditions of the study year. Given varying field challenges in different water conditions, specific sites and gears may be subject to change across water year types. Otolith geochemistry methods from Year 1 will be expanded to determine the reliability of such signatures in different hydrologic conditions. The multi-year effort would allow the evaluation of the effects of different water year types (e.g. hydrologic conditions in the tributaries during the spawning/early rearing period) on smelt reproduction, and to follow individual cohorts to adulthood.

These studies would be initiated in Year 1 of the research program and would continue potentially through Year 5 depending on results of initial sampling and analyses and hydrologic conditions that occur during the spawning and early larval rearing period each year. A general timeline for sampling and reporting is provided in Table 1. All progress and final reports will be provided to both the IEP PWT and the Longfin Smelt Technical Team.

Longfin Smelt Vertical Migration Behavior *(Questions #7-8)*

A second set of studies will examine the degree to which Longfin Smelt behavior, and thus their catchability by survey nets, may be affected by factors such as turbidity, tidal cycles, and any diel movements of Longfin Smelt. Such behaviors could substantially influence the interpretation of long-term data sets such as the FMWT. The initial effort will focus on evaluating existing FMWT and Bay Study data sets to examine whether there is evidence of substantial variability in fish catch related to the environmental variables of interest. Results of the analysis of existing monitoring data from the FMWT, Bay Study, and other data sources have the potential to identify sources of variability of abundance indices that could affect the interpretation of long-term trends in indices of abundance. If relationships are detected and they are of sufficient magnitude to influence data interpretation, then field studies will be planned to further quantify the results. Once additional field studies are identified, the IEP PWT will detail the study objectives, methods, and projected take of Longfin Smelt in a separate study plan that will be reviewed by newly created Longfin Smelt PWT and Technical Team, and subsequently by the IEP Management Team.

Based on initial analyses and logistical planning efforts, the additional studies proposed would attempt to directly address the potential effects of diel, tidal, and turbidity on variation in Longfin Smelt catch. Currently, we anticipate that any additional field effort would occur during the fall months (September-December to coincide with FMWT sampling or other times as appropriate, identified during refinement of the study design and study plan development) at designated locations using the Bay Study MWT and otter trawls during the day and during the night. Sampling locations will be chosen to reflect the wide geographic distribution observed for Longfin Smelt and will include one or more stations in the lower Sacramento River near Sherman Island, one or more stations in Suisun Bay channel, one or more stations in San Pablo Bay, and one or more stations in central San Francisco Bay.

The analyses of existing datasets will start in Year 1. Based on results of the initial data analysis, further experimental field studies to collect specific data (e.g., day vs. night collections with the MWT and otter trawl) may be conducted beginning in year 2 of the study. A general timeline for initial analyses, sampling, and reporting is provided in Table 1. All progress and final reports will be provided to both the Longfin Smelt PWT and the Longfin Smelt Technical Team.

Description of Tasks

Task 1: Adult Fish Sampling in Bay Tributaries (Principal Investigator: James Hobbs, UC Davis)

Year 1: Reconnaissance Sampling

The UC Davis research group will base fish sampling in Bay tributaries for this project on recent experience gained conducting the ongoing South Bay Salt Pond Restoration Fish Monitoring Program as well as many other fish surveys in the estuary and elsewhere. For this project, we will sample Sonoma Creek, Petaluma River, Alameda Creek and Coyote Creek, and potentially other areas if deemed likely to be sites of Longfin Smelt spawning by the Longfin Smelt PWT and Technical Team. During the first year, adult sampling will be conducted to find regions with the highest likelihood of finding adult and larval Longfin Smelt. This will be considered the pilot project year. Sampling will occur during the months of January-February, when fish are most likely to be ripe and ready to spawn. This will not provide evidence of successful spawning; however, it will allow us to target locations where the probability of finding larvae is high for larval sampling, rather than taking a shot-gun approach and sampling all locations over many months with a larval plankton net, creating a large volume of plankton to sort and larval fish to identify. The goal of this approach is to increase efficiency and reduce costs.

Years 2-4

Based on the pilot year results, we will determine a sampling design for the following four years of the project that will maximize success of locating adult and larval Longfin Smelt during the spawning season. Larval sampling is described below. With full funding of this project, we propose that adult Longfin Smelt sampling occur monthly from October to March using a four-seam otter trawl with a 1.5 m X 4.3 m mouth opening, a length of 5.3 m, and a mesh size of 35-mm stretch in the body and 6-mm stretch in the cod end. To sample shallow waters (less than 1.5-m), we will run a trawl behind a medium sized boat (we currently use a 26-ft Bayrunner modified for trawling). A 16-ft shallow bottom tracker boat will be used to tow a small four-seam otter trawl with a mouth size of 2.44 m x 0.75 m, a length of 3 m, a mesh size of 32-mm stretch in the body and 6-mm stretch in the cod end. Paired samples using the two collection methods will be made periodically during the study to determine comparative gear collection efficiency. Preliminary side-by side comparisons have been conducted in Coyote Creek as part of the South Bay Salt Pond Restoration Fish Monitoring Program (*Hobbs unpublished data*), with some mixed results. In general, however, the smaller net scales in volume to the larger net. In addition, larger, slower moving fish have been caught with the smaller trawl, but large mobile species like striped bass may be able to avoid the small net. We have caught similar numbers of adult Longfin Smelt with the smaller trawl compared to the larger trawl. In three years of trawling in the Alviso-Coyote Creek complex we have conducted 42 trawls from Oct to March that have netted a total of 229 adult longfin smelt.

Within each tributary, otter trawl stations will be stratified by salinity (1-3ppt, 4-6ppt and ~12-ppt) where spawning staged Longfin Smelt have been found historically. A total of 2-3 replicate trawls will be made per stations per Bay tributary on a monthly basis in the initial pilot year of the investigation. Up to 100 adult longfin smelt from each Bay tributary will be archived for otolith analysis.

Based on results of initial trawl replication and take permissions, modifications to sampling frequency and locations will occur for subsequent years. Along with otter trawl sampling, longitudinal profiles of water quality with be conducted at each site using a Hydrolab 5S, connected to a Trimble GPS unit to record a gradient of water quality parameters associated with adult fish catch (occupancy). Water samples will also be collected from the various tributaries sampled for use in developing a baseline for determining the potential for unique geochemical signatures on both a regional scale and tributary-specific scale for comparison with collected otoliths.

Representative samples of adult Longfin Smelt will also be collected as part of routine Bay Study sampling. Longfin Smelt adults collected from a variety of locations represented by Bay Study sampling locations will be used to assess geochemical signatures. The initial phase of the otolith assessment of adult Longfin Smelt will include a target sample size of 100 adults for analysis. Sample sizes will be refined based on results of initial analyses.

Task 2: Larval Fish Sampling (Principal Investigators: James Hobbs, UC Davis; Bob Fujimura, DFW)

Task 2a:

DFW currently conducts a Smelt Larval Survey (SLS) in winter and early spring (January-March) using a ski-mounted plankton net in the upper San Francisco Estuary[1] . Such gear is too large for sampling smaller Bay tributaries, so a smaller diameter net is proposed to be used for routine larval collections in the small and shallow tributaries. As part of developing the comparative baseline for this study, the smaller net will be used in parallel with the standard DFW SLS sampling nets to assess comparative collection efficiency. For the DFW portion of Task 2, the DFW SLS study will extend larval smelt sampling into the lower reaches of the Napa River and conduct a single ichthyoplankton tow at 10 stations biweekly beginning in early January and ending late March. Expansion of the DFW larval smelt surveys into the Napa River provides the opportunity to develop estimates of larval density and abundance for the Napa River to compare with similar estimates for the upper Estuary, as well as to conduct a series of paired sample collections to develop the data necessary to allow a comparison of relative densities in

[1] http://www.dfg.ca.gov/delta/projects.asp?ProjectID=SLS

Bay tributaries to other locations sampled by the SLS. These paired samples will be collected in February and March during two of the biweekly surveys conducted by the DFW SLS during the first year both studies conduct fieldwork; based on results additional samples may be required. Samples collected during this paired sampling will be preserved in 10% buffered formalin to facilitate fish size comparisons between gear types.

<u>Task 2b:</u>

Year 1: Pilot Project

For the UC Davis portion of Task 2, in addition to the side-by-side gear efficiency testing, several additional Bay tributaries will be sampled for larval Longfin Smelt including Sonoma Creek, Petaluma River, Alameda Creek and Coyote Creek. In the pilot year, only tributaries where adults were observed will be sampled from January to March bi-weekly.

Larval fish will be sampled using a replicate DFW SLS net if possible with our current boat otherwise we will use our standard a 0.75-m diameter x 3-m length, 505 µm mesh, General Oceanics plankton net with a 1-L cod end jar with 250-micron mesh bottom. The net will be towed by a 26-ft Bayrunner , in an oblique fashion for 10-minutes starting at the bottom of the water column and bringing the net up 1/5 of the depth every 1 minute. Water volume sampled will be determined with a General Oceanics flow meter, recording serial numbers before and after each tow and using the General Oceanics algorithm to calculate volume of water sampled[2]. Three replicate tows will be conducted at freshwater sites and where available at sites having salinities of 1-3ppt, 4-6ppt and ~12-ppt. The contents of the sample will be washed into the cod-end jar and preserved in 95% ETOH or 10% buffered formalin, so that otoliths could be used from collected samples, and labeled accordingly. Water quality vertical profiles will be measured with a YSI-6000 water quality meter for electrical conductivity, salinity, water temperature, dissolved oxygen and pH.

Larval fish will be separated from detritus and other organisms under a class 100 fume hood and stored in 25-mL glass vials with fresh 95% ETOH. Larvae will be identified to the lowest taxonomic level, enumerated and measured for length to the nearest 0.1mm under a stereo microscope fit with an ocular micrometer. Fish identification will follow the dichotomous key and taxonomic features using the "Tracy Fish Facility Studies: Fishes of the Sacramento-San Joaquin River Delta and Adjacent Waters, California, A Guide to the Early Life-History, Volume 44-Special Publications, December 2010". All larval fish will be reported in units of fish per 1,000 cubic meters of water sampled to be consistent with DFW smelt survey results. Data for the detections of Longfin Smelt larvae and post-larvae will be reported to DFW within 5 business days to ensure the required sampling frequency is conducted.

[2] http://www.environmental-expert.com/products/model-2030-flowmeter-17301

Figure G. RV Triakis with zooplankton net and otter trawl deck over the motor.

Task 3: Otolith Geochemistry (Principal Investigator: James Hobbs, UC Davis)

Using the unique geological properties of watersheds and tributaries to the San Francisco Bay and the Central Valley measurements will be made of the chemical elements and isotopic ratios of many trace and minor elements from various tributaries sampled and compared to otolith geochemistry signals. Dr. Hobbs' UC Davis research group has been conducting this research for over 10 years and has created a geochemistry "road map" of the San Francisco Bay to distinguish different tributaries that serve as natal origins for several native species, including Splittail, Delta Smelt and Longfin Smelt (Hobbs et al 2005, 2007, 2010, Feyrer et al 2007). Using laser ablation inductively coupled plasma mass spectrometry (ICPMS) and multi-collector ICPMS, measurements can be made of the chemical composition of fish otoliths to less than weekly resolution in some species (e.g. Delta Smelt). Thus far, the Hobbs lab at UC Davis has been able to reliably identify natal origins of Central Valley and the Napa-Petaluma stock of Splittail, natal origins and life history of Delta Smelt, and the salinity history of Longfin Smelt (Figure H). Research to date on Longfin Smelt has shown the ability to definitively show that individuals surviving to the adult stage and returning to the spawning grounds of the Sacramento-San Joaquin confluence were derived from fish that had reared in the low-salinity zone (1-3ppt). Hobbs has also compared retrospectively the rearing areas of successful recruits to the distribution of Longfin Smelt larvae collected in the 20-mm survey and has shown that a large proportion of fish that reared in salinities greater than 6-ppt did not return as adults to the confluence spawning grounds; presumably they did not survive.

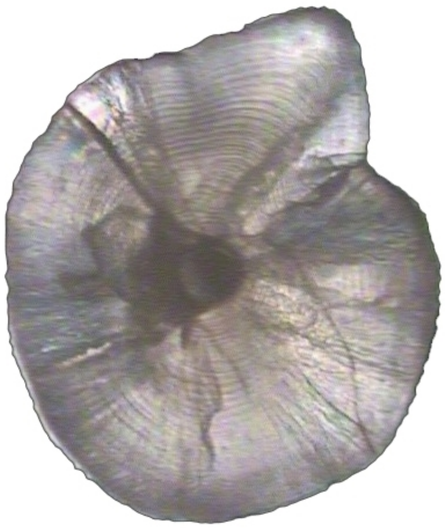

Figure H. Longfin Smelt otolith with a 40 µm laser spot on the natal core.

In this study, we propose that the initial "road map" of geochemistry further developed by the Hobbs lab be expanded to include additional Bay tributaries where Longfin Smelt may spawn and rear as larvae (e.g. Coyote Creek in South Bay). Using facilities at UC Davis (The Interdisciplinary Center for Plasma Mass Spectrometry; http://icpms.ucdavis.edu/), it is proposed that up to 52 trace and minor elements be measured using the Agilent 7500ce, in addition to measurements of the isotopes of several elements that can further be used to help resolve differences in the geochemical signatures among tributaries, including strontium isotopes and lead isotopes. In addition, it is proposed that the project quantify the isotopic composition of oxygen, carbon, nitrogen and sulfur at the UC Davis Stable Isotope Facility (http://stableisotopefacility.ucdavis.edu/). Details of the proposed analytic methods for these geochemical measurements have been reported in previous publications (Hobbs *et al.* 2005, 2007, 2010, Feyrer *et al.* 2007 and at the UC Davis ICPMS website).

Natal Tributary Origin

Year 1: Pilot Project

Water samples from Bay tributaries will be collected by UC Davis in triplicate in each salinity zone sampled during the spawning and larval rearing periods (January-March). Otoliths from larval and adult Longfin Smelt from tributary collections during the pilot year (up to 100 per lifestage and tributary) will be extracted and polished for laser ablation geochemistry analysis to determine Bay tributary chemical fingerprints. In addition, otoliths will be aged;

daily for larval fish and annual for adult fish. These analyses will also be initially performed on approximately 100 juvenile and adult Longfin Smelt collected as part of the routine San Francisco Bay Study sampling program.

Results of the initial year of investigation will be critically reviewed by the proposed IEP Project Work Team and used to refine the sampling program and otolith analysis in subsequent years of this investigation.

As this is a pilot project, a precise estimate of the minimum sample size for larval, and adult stage catch, or number of otoliths required to be examined cannot be provided at this time and will need to be developed based on initial results and could likely depend on the numbers of fish collected in Bay tributaries. From previous research conducted by UC Davis a minimum sample size of at least 25 larval and adult fish, as well as up to 6 water samples per Bay tributary would be required to discern unique chemical signatures to have project success. The targeted sample size for this study includes up to 100 juvenile and adult Longfin Smelt collected as part of the DFW Bay Study sampling program in addition to the water and larval and adult Longfin Smelt collected from the various tributaries sampled.

Adult Ocean Residency

Several studies, including the San Francisco Bay Study and a peer reviewed publications (Rosenfield and Baxter 2007), have suggested that adult Longfin Smelt (age 1+) may venture outside of the San Francisco Bay proper into the nearshore ocean. Collections by the San Francisco Bay Public Utility Commission, the NOAA Fisheries Ocean Midwater Trawl Survey and collections at the Bodega Marine Laboratory in the 1970's have captured Longfin Smelt in the nearshore ocean outside of San Francisco Bay. The use of otolith geochemistry to determine if a fish has resided in the nearshore ocean has been examined by several researchers with equivocal results. The use of several trace and minor element ratios has been useful for distinguishing both upwelling hotspots in central and northern California, (e.g. Pt. Reyes, Bodega Head vs. Monterey) (Brian Wells *unpublished data*), and distinguishing Central from Southern California (Nishimoto et al 2010).

In addition to trace and minor elemental ratios differences between San Francisco Bay and the nearshore ocean, other constituents of water could be examined to distinguish nearshore habitats from San Francisco Bay. Rosenfield and Baxter (2007) observed the Longfin Smelt abundance significantly decline in the late summer when Bay water temperatures are highest, consistent with the thermal tolerance of the species, meanwhile nearshore habitats would be several degrees cooler in the summer compared to the Bay due to ocean upwelling of cool, deep, nutrient-rich waters which are also comprised of high concentrations of many trace and minor elements. Oxygen isotope ratios have been used for decades to determine the temperature history of fish, as the lighter isotope of Oxygen ^{16}O is lost to evaporation in warmer waters relative to the heavier ^{18}O isotope, thus a well-established relationship between water temperature and otolith ^{16}O:^{18}O has been established (Devereux I 1967). Oxygen isotope ratios could be used to reconstruct the temperature history of Longfin Smelt and the corresponding derived temperatures during the hypothesized ocean phase could be compared to Bay temperatures. This alone may not infer ocean residency; however combined with trace and minor element ratios associated with upwelled waters could, in combination provide evidence for ocean residency.

Lastly, the variability of strontium isotope ratios ^{87}Sr:^{86}Sr during the potential ocean phase could also be used in combination with the above methods to infer ocean residency. In our research with Longfin Smelt and other migratory species such as Chinook salmon and Steelhead in the central valley, we have observed that fish that make ocean migrations, such as Chinook salmon, exhibit much less variability of strontium isotope ratios ^{87}Sr:^{86}Sr compared to species such as YOY Longfin Smelt or striped bass which rear in San Francisco Bay or make frequent movements into different salinity environments. Thus, variability of the strontium isotope ratios in conjunction with other element and isotope ratios could be used in combination to infer ocean residency.

While we may not be able to collect Longfin Smelt in the nearshore ocean, we may be able to acquire samples from the NOAA Midwater Trawl Surveys. We would also examine otoliths of a similar species, the night smelt (*Spirinchus starksi*), Surf Smelt (*Hypomesus presiosis*) which are commonly captured off of Bodega Bay. Examining these otoliths from species known to reside in the ocean could be used as a proxy validation of the suite of element and isotope ratios to infer ocean residency. Given the availability, Longfin Smelt could be held in raw seawater at the Bodega Marine Laboratory (BML), where ample fish culture facilities exists, and a long-term monitoring of trace and minor elements is conducted in the nearshore environment in front of the marine lab. The flow-through seawater system at BML draws water from the nearshore environment and all environmental conditions could be maintained to mimic nearshore ocean rearing. The latter possibility of laboratory rearing will be further developed during Years 2-5 of the project if deemed worthwhile by the Longfin Smelt PWT and Technical Team.

Task 4: Effects of environmental variables on Longfin Smelt behavior and catch (Principal Investigators: Data analyses: Dave Fullerton (SWC) and Chuck Hanson (Hanson Environmental, Inc.); Follow-up field sampling: Randy Baxter (DFW); Other PIs to be determined (e.g. if SmeltCam is used)).

The initial effort (Year 1) would involve an exploratory review of existing data sets to determine whether Longfin Smelt catch varies substantially with several environmental variables. Specifically, we would look at the relative catch in concurrent Bay Study MWT and otter trawls, reflecting upper and lower water column catch, respectively. The general approach will be to look at individual surveys and ratios (e.g. Bay MWT/otter) to examine whether there is evidence that total catch or position in the water column varies based on diel, tidal, seasonal, and water transparency changes. The data may be stratified by salinity class and time periods (e.g. pre- and post-POD) to provide some degree of standardization. The initial approach would be graphical, but basic statistical models will be applied as appropriate.

Depending on the results of the exploratory analyses and guidance from the proposed IEP Project Work Team, field studies may be conducted to provide higher resolution data on fish behavior in relation to the environmental variables of interest. However, experimental sampling within the Bay-Delta estuary at night includes a number of logistic and safety concerns. Given these concerns it is recommended that experimental sampling during the day and at night for Longfin Smelt be conducted as part of the proposed suite of studies included in this proposal; however, it is recommended that initiation of the experimental sampling should be delayed until at least the fall of 2015 (Year 2 of the studies). The one-year delay in initiating these studies provides an opportunity to develop a stronger experimental design and experimental sampling protocol, and to estimate and obtain approval for take of ESA fishes, as well as time to plan for the safe implementation of this sampling effort, while minimizing the potential for impacts of the experimental sampling on DFW staff and other fishery sampling programs.

Although the exact details of a field effort remain to be determined, we provide some information about a possible sampling scenario that might be considered. The likely approach would be sampling during the fall months (September-December to coincide with FMWT sampling or other times as appropriate in refining the study design and study plan development) at designated locations using the Bay Study MWT and otter trawls deployed by the RV Longfin during the day and during the night. In addition, the study may include a geographic component such as: one or more stations in the lower Sacramento River near Sherman Island; one or more stations in Suisun Bay channel; one or more stations in San Pablo Bay, and; one or more stations in central San Francisco Bay. Stations would be selected to test a range of turbidity levels. Also, the trawls may be deployed at multiple depths at each station to assess variation in vertical distribution of smelt within the water column. Consideration will also be given to using a net design that would allow fish collection only at prescribed depths. An alternative sampling design that would be applicable for surveys in San Pablo and San Francisco bays, where the greatest majority of Longfin Smelt occur, may be the use of the Smelt-Cam (Feyrer *et al*. 2013) to assess changes in vertical distribution, while reducing the need to collect and harm Longfin Smelt. These additional potential field studies would be designed to be initiated in year 2 or later of the research program.

Task 5: Project management and reporting

UC Davis: James Hobbs.
DFW: Bob Fujimura and Randy Baxter

Overall contract and invoice management for Longfin Smelt distribution and abundance investigations conducted by UC Davis and DFW will be conducted by UC Davis and DFW project personnel associated with each task. Administrative support will be supplied by the Wildlife, Fish and Conservation department at UC Davis. The lead investigator will manage the operations of field and laboratory work. The lead investigator will be responsible for the management and training of staff and student assistants for the study and provide periodic performance evaluations according to University of California policy. The lead investigator will also be responsible for the safety of staff in the field.

Project management of the SLS sampling extension into Napa River (Task 2a) is the responsibility of Bob Fujimura. Coordination of this sampling with UC Davis for gear comparison will be the responsibility of Randy Baxter, and will be accomplished in part through the creation of a Longfin Smelt PWT and Longfin Smelt Technical Team. Randy Baxter will also be responsible for reporting on the density and abundance of Longfin Smelt larvae in Napa River in relation to the upper Estuary.

Project management of Longfin Smelt vertical migration investigations would be the responsibility of the State Water Contractors (Dave Fullerton, Chuck Hanson) and DFW (Randy Baxter). Contract management and management oversight of the initial analytical investigations will be coordinated between the principal parties based on specific tasks and responsibilities. Initial analytical efforts and reporting will be the responsibility of Chuck Hanson. If analyses determine that Longfin Smelt catch appears to be related to one or more of the factors listed and the variation is substantial enough to influence abundance indices, then additional field sampling will be planned and conducted with Randy Baxter as the responsible party of DFW personnel and logistics coordination; Dave Fullerton, Randy Baxter and Chuck Hanson for study design, data analysis and reporting.

The proposed IEP Longfin Smelt Project Work Team and Longfin Smelt Technical Team will provide guidance and assistance for all of the proposed studies, review of analyses and results, and assist in identifying refinements or additions to the proposed scope of investigations.

Data analyses

Research Questions 1 (Bay tributary spawning) and 2 (Differences between wet and dry years).

If adult Longfin Smelt are detected in tributary sampling, then the catch-per-unit of effort (CPUE) from the otter trawl catch at different Bay tributaries (and potentially other Bay Study locations) will be compared using general linear modeling, with environmental variables as covariates, such as salinity, temperature, turbidity etc (Question 1). In addition, variables such as freshwater outflow from the Delta or water year type will be assessed to address Question 2. The analysis may also use occupancy modeling because catch is likely to be low and the CPUE data not normally distributed. Occupancy modeling can take frequency of occurrence “occupancy” and environmental variables into consideration simultaneously using a maximum likelihood approach. Statistical significance can be assessed by an iterative Markov-Chain Monte Carlo simulation of the raw data to provide for a more robust assessment of certainty regarding the presence or occupancy and environmental drivers associated with occupancy.

Research Question #3 (Contributions of Bay tributaries to overall population).

Larval data will be summarized based on density (e.g. #/1,000 m^3) within the range of lengths effectively captured by both gears (derived from parallel sampling with DFW SLS and determination of size-specific collection efficiency of the two sampling nets) and compared to SLS samples in upstream areas adjusting for differences in habitat area or volume among sampling sites. Initial comparisons will be based on ANOVA among the different geographical locations and study years. Absolute abundance estimates will be generated based on the volume of each geographic area (Newman 2008). Additional analyses of population abundance based on salinity ranges will also be considered to provide a measure of the potential relative contribution of different geographic areas to the larval population. Because the proposed sampling program will be coordinated with DFW SLS surveys, density data can be translated into estimated larvae present in Suisun Bay and the confluence area (i.e., make direct comparisons of habitat volume and area weighted density) and assess the proportional contribution to the larval abundance. Regional volume estimates are available based on hydrologic models (Newman 2008; and from current modeling work). The contribution of Bay tributaries

Research Questions #3 (contribution of tributaries and regions to juvenile and adult age classes), #4 (unique geochemical signals of tributaries), and #5 (regional contributions to juvenile and adult age classes).

Chemical signatures from the study tributaries will be assessed from water samples and fish otoliths using a suite of multivariate ordination statistical tools, canonical cluster analysis and discriminant function analysis. Water quality parameters such as water temperature, electrical conductivity, and salinity will be included as co-variates in the models to determine the cause of unique chemical signatures of Bay tributaries. The otolith chemistry of recruited juvenile and adult fish collected in DFW Bay Study and FMWT sampling and those collected as part of the proposed surveys could then be examined to determine the proportional contribution of different spawning and rearing areas and regions to the juvenile and adult populations. A maximum likelihood mixed stock model (Hobbs *et al*. 2007) will initially be used to determine the natal source.

Research Question #6 (Ocean Residency).

Chemical signatures from the Bay and nearshore ocean will be assessed from water samples and fish otoliths collected in the Bay by the SF Bay Study, and UCD, and from nearshore samplings by NOAA Fisheries Midwater Trawls and lab validations of fish held at the Bodega Marine Laboratory. Similar statistical approaches (notably discriminant function analysis) will be employed as in questions 3-5.

Research Questions #7 (vertical migration with tidal cycle) and #8 (effect of water clarity on FMWT, BMWT, and OT).

Using existing data, graphical and basic statistical analyses will be used to address Questions 7 and 8 (influence of time of day, tidal cycle, and water transparency on Longfin Smelt catch). The exact approach to analyses of new field survey data depends on the results of the exploratory data analyses, plus the methods developed by the study team. However, the analytical approach of Feyrer *et al*. (2013), in which models predicting the effect of water quality variables on Delta Smelt catch were compared, offers a suggestion of how osmerid data collected during fall could be statistically evaluated.

Estimated Take

This study will rely heavily on samples collected from existing IEP sampling programs (FMWT, Bay Study, Smelt Larval Survey) and existing take. Additional take would occur as a result of SF Bay tributary sampling. Take for UC Davis San Francisco Bay tributary sampling will be covered under the individual permits for the lead investigator (Hobbs) for SF Bay tributary sampling. The current Memorandum of Understanding between the California Department of Fish and Wildlife and U.C. Davis will be amended to include lethal sampling of a subsample of pre-spawning adult Longfin Smelt to assess reproductive condition and collect otoliths for geochemistry analysis.

Estimated additional ESA take for the expansion to the DFW Smelt Larval Survey is as follows:

Longfin Smelt: larvae – 9,000, juveniles – 20, adults -2.

UCD
Estimated Longfin Smelt take based on 3 years of preliminary study:

Coyote Creek -100 adults, juveniles 1000
Napa River – 100 adults, juveniles 2000, Larvae 9000
Sonoma Creek– 100 adults, juveniles 2000, Larvae 9000
Petaluma River -10 adults, 100 juveniles, 100 larvae
Alameda Creek - 20 adults, 200 juveniles, 500 larvae

Salmonids and sturgeon: No take is requested.

Delta Smelt: larvae – 10, adults –2. Existing Delta Smelt take coverage for SLS [derived from NBA sampling and very high] is sufficient to cover this new work.

UCD
USFWS Permit to J. Hobbs 5/31/13-5/30/2017 for the Napa River TE97450A-0 50 Adults 150 larvae/juveniles per year

No take for Delta Smelt will be requested for Sonoma, Petaluma, Alameda, Coyote Creek. Take for Delta Smelt may be required for (this is currently be ascertained by looking at existing data from the Suisun Marsh project).

Timeline

The current proposal focuses on the first year, when key methods will be established and analyses will be conducted to modify the approach as necessary. However, the anticipated timeline for the full study is relatively long (5+ years) because: 1) a key part of the design is to compare results for wet and dry years, which occur at unpredictable frequencies; and 2) understanding the sources of Longfin Smelt recruitment will be most effective if there is sampling at the larval stage (to determine the initial production areas), followed by analyses of sub-adults and adults from the same cohort 1-2 years later (to determine which fish recruited to the population). The proposed timeline is provided as Table 1.

Feasibility

As noted above, much of the sampling would be based on existing IEP surveys, so other field sampling along the same lines (i.e., Napa River sampling) is highly feasible. The Hobbs research group has been successful with proposed techniques in some south Bay tributaries and in South Bay salt ponds and embayments, so these can be adapted to other tributaries with some advanced reconnaissance. In particular, Hobbs et al. have a long history of sampling in shallow waters of South San Francisco Bay (Coyote Creek and Alviso Slough/Guadalupe River) using otter trawling methods developed in Suisun Marsh's 30+ year monitoring program (Hobbs et al. 2012). In addition, Hobbs et al. have been conducting zooplankton and larval fish sampling in South San Francisco Bay. The Hobbs group already holds a Memorandum of Understanding with DFW for sampling Longfin Smelt in both Coyote Creek and the Napa River and a federal take permit for Delta Smelt in the Napa River. The Hobbs lab would be able to conduct a limited amount of work with existing funds; however those efforts would only cover Coyote Creek bi-monthly and the Napa River for 3 months.

Importantly, the proposed timeline depends on the ability to execute contracts to UC Davis and DFW supplemental field sampling. If the contracts cannot be executed very early in 2014, additional SF Bay tributary sampling may not be possible in winter-spring 2014 and the entire study would be delayed by a year.

Deliverables

The schedule of reporting for each task is provided in Table 1. All reports will be provided to the IEP Longfin Smelt PWT and the Longfin Smelt Technical Teams to be formed in Year 1. As the present study design is primarily a pilot project to assess spawning and rearing of larvae in Bay tributaries during the first year of what is expected to become a longer-term investigation, the primary deliverable from this pilot effort will be a report detailing findings from reconnaissance work and a detailed study plan for the remainder of the study. During Years 2 – 4, annual progress reports detailing sampling activities and preliminary findings will be submitted for Bay tributary sampling and nearshore ocean rearing (UCD), and Napa River sampling (DFW). At the end of Year 4 or in the Winter-Spring of Year 5 (depending on whether final sampling efforts take place in Year 3 or Year 4, final reports for each task will be completed (Table 1).

The Napa River larva sampling effort (Task 2a) will result in data added to the current SLS database, which will be available via DFW's FTP site, and a summary report describing the density and abundance (absolute estimate for the river reach sampled) for the river compared to the upper Estuary for each year of the sampling effort through Year 3. After Year 3 the utility of this work will be re-assessed. Gear comparison results will be used to establish the size range of Longfin Smelt larvae in which both gears are effective, and that range used for comparative abundance reporting. Reports detailing the densities and abundance estimates for Bay tributaries in relation to the Napa River and upper Estuary will be provided to the Longfin Smelt PWT and Technical Team by fall following sampling (fall Year 4).

Assessment of Longfin Smelt vertical migrations will initially involve a detailed analysis of a Bay Study dataset containing paired MWT and OT samples to determine if catches in the MWT are associated with any of the factors listed. This effort will result in a report providing detailed description of the data, data manipulation and analyses conducted, followed by results and an assessment of whether vertical movement appeared to occur and if the magnitude was such that it could influence abundance indices and additional sampling would be necessary to more accurately assess the effect. This report would be submitted to the Longfin Smelt PWT and Technical Teams, and its review and acceptance would initiate discussion of next steps and study design for field sampling. In addition and if necessary, a detailed study plan for field studies to investigate Longfin Smelt vertical migration will also be submitted at the end of Year 1.

Assuming that the study is successful, we anticipate that at least two peer-reviewed scientific papers would be produced by the study. Initial papers are most likely to be based on methodology (e.g. tributary and oceanic otolith signatures; using estimates of absolute abundance to estimate contribution to the larva population), while later publications addressing the contribution of Bay tributaries to the adult population would require several years to develop meaningful results to describe sources of recruitment.

Project Coordination

The study would receive input and guidance from the proposed new IEP Longfin Smelt Project Work Team that would be chaired by a DFW team member. PWTs are open to the public, but we expect that at a minimum, the group would include scientists from DFW, DWR, UC Davis, and State Water Contractor staff involved in the development of the current proposal, as well as other interested agencies and stakeholders. Major changes and additions to the study plan, such as field investigation of Longfin Smelt vertical migration, will require development of new study plans that will be reviewed by IEP Management and Coordinator Teams. Project direction and coordination will be managed by the Longfin Smelt Technical Team that will be convened with at least one representative from DWR, SWC, and DFW.

Budget

The budget provided in Tables 2a and 2b is an estimate of total costs to conduct the proposed study for an initial pilot study year. In summary, the total budget (including CDFW and UCD components, as well as IEP in-kind contributions) for Year 1 is approximately $842,708; however, given potential budget contingencies for UC Davis (described below in the budget justification), the Year 1 budget could increase to $955,641 (Budget Summary table, attached in Excel spreadsheet).

This budget is meant to allow for a maximum effort in Bay tributaries at appropriate times and potentially other locations depending on information developed from initial testing and analyses. The proposed budget costs are presented separately for each task. Although there is some overlap in the timing of sampling that could reduce labor costs, the proposed budget would provide for researchers to be at multiple sites and for extended periods of time to assure detailed monitoring occurs in each of the designated of Bay tributaries sampled as part of this investigation. The budget will be refined in future years based on results of the initial year of sampling and analyses.

While this study will not be formally funded by IEP, it will require substantial in-kind contributions from IEP personnel, in the form of consultation and participation in the IEP PWT, project management (including potential for contract management), as well as field sampling (Task 2b). All foreseeable tasks associated with project management and Task 2b for Year 1 are detailed in Table 2. Additional IEP in-kind contributions (guidance, consultation, management, and communications) are estimated below. These are maximum time estimates for Year 1, assuming IEP personnel are tasked with creating and managing contracts, and will be actively involved with guiding the project through coordinating the IEP PWT and Longfin Smelt Technical Team.

Dr. Ted Sommer (DWR): approximately $20,000 (10% time)
Dr. Louise Conrad (DWR): approximately $40,000 (20% time),
Randy Baxter (DFW): approximately $17,000 based on about 10% time

Budget Justification for UC Davis portion (Principal Investigator, Dr. James Hobbs, Tasks #1-3, 5, Table 2a)

The proposed budget for salary and benefits includes the lead P.I. Dr. James Hobbs at a total of 50% as Dr. Hobbs has other contractual obligations to IEP funded projects with Delta Smelt. Additional staff includes 2 Junior Specialists at 50% time in the pilot year, which would run from December 2013 to March 2014 for field work, and a Staff Research Associate to serve as the lead field biologist, boat captain and to assist with staff management. We have included up to 4 undergraduate assistants to help with field work and set-up and clean-up of field gear prior to and post sampling. The Junior Specialists hired for field work would spend the remaining 50% time in the laboratory, sorting and identifying larval fish. This task will include an additional four undergraduates to assist in the picking and sorting of fish larvae for enumeration and species identification. The otolith chemistry task would be conducted by one additional Junior Specialists at 100% time and a Graduate Student Researcher at 100% time in the summer (3mos) and 50% time during the school year (9mos). This task would begin shortly after samples are collected but would extend through the summer and fall for preparation of samples for age, growth and otolith chemistry analysis. We propose to hire one additional Junior Specialists that would be dedicated to this task, along with two additional undergraduate assistants. A contingency to sub-contract the larval fish sorting and identification to an outside consulting firm would leave the field crew at only 50% for the pilot study. Dr. Hobbs would make up the remaining 50% time with other IEP work, including Delta Smelt otolith work. Thus, in total this project would employ 3 fulltime Junior Specialists, 1 Graduate Student Researcher, 10 undergraduate assistants, 1 Staff Research Associate at 50% time, and the lead PI 50% time.

The personnel portion of the proposed budget includes fringe benefits rates for the current academic fiscal year which runs from June 30th- to July 1 and would likely span across the start date of the study, thus when the contract is written and a start date is determined the budget may change due to small changes in the benefit rates for employees. Overhead rates for both State and Federal overhead are also included. The Federal overhead rate schedules for the next three fiscal years have been submitted to UC Davis with small increases in the rate over the next three fiscal years. The State rate is also subject to change.

The budget provided in Table 2a is for the pilot year of this study, which will scout out all potential study sites, determine safety related issues to each site and station. The costs associated with the Year 1 pilot study are best estimates at total costs for each task of the project and may change with better information regarding feasibility of study sites, stations within study sites, and the number of samples and trawls that can be accomplished in the allotted time per site. As Year 1 fieldwork is largely reconnaissance, it is not possible to develop a detailed budget for Years 2-5, as it will depend on the location and number of sampling sites to be determined in Year 1.

Two budget contingencies are included in the Year 1 study plan: (a) Equipment for Task 1 (1d in Table 2a): potential need for a new boat and motors; and (b) Larval fish sorting (Task 2 in Table 2a): it may be necessary to sub-contract of the zooplankton sorting for larval fish, enumeration and identification of all larval fish in the sample to Tenera and Associates. Sub-contracting may not be necessary if use of the proper equipment can be negotiated with the UC Davis Center for Watershed Sciences.

Finally, the Hobbs laboratory proposes that the Year 1 pilot study begin survey work on December 1 2013 and run through November 30 2014. This timeframe would require the contract to be written with a retroactive start date of December 1. Additional funds in year 2014-2015 will be requested to continue the study based on results from Year 1, and with a refined study plan. Lastly, note that the proposed pilot year may occur during the winter following one of the driest years on record, while future sampling years may be much wetter hydrologically, potentially incurring additional equipment, maintenance, or personnel costs.

Salary and Benefits

Task 1: Field Sampling (UCD Field Labor, Adult and Larval Longfin Smelt Sampling)

Task description: Conducting field surveys the distribution and abundance of adult and larval longfin smelt in the Napa River, Somoma Creek, Petaluma River, Alameda Creek and Coyote Creek monthly from December 2013 to March 2014. All fish data will be recorded and water quality transects measured and recorded for each site, with up to 6 stations per site.

Staff:

Lead Scientist Dr. James Hobbs (Assistant Research Scientist II) will spend 10% of his time overseeing and training staff for task 1, at a monthly salary $6,508 and benefits rate of 35.7% from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Staff Research Associate II, will spend 25% time at a monthly rate of $3,562, and a benefits rate of 0.51% as estimated for the calendar year 2014-2015 from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Jr. Specialist II (A) will spend 50% time at a monthly salary rate of $3,082, and benefits rate of 35.7% as estimated for the calendar year 2014-2015 from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Jr. Specialist II (B) will spend 50% time at a monthly salary rate of $3,082, and benefits rate of 35.7% from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Jr. Specialist I (A) will spend 50% time at a monthly salary rate of $2,890 and a benefits rate of 35.7 from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Undergraduate Lab Assistants we will employee 4 undergraduate students for a max of 10hrs/ week or 25% time @ $9.00/Hr. and a benefits rate of 1.3% from January 1, 2014 to December 31, 2014.

Task 2a: Larval Fish Sorting (This budget is for UCD to do the processing)

Task description: sample sorting of plankton for larval fish and identification of larval fish to species.

Staff:

Lead Scientist Dr. James Hobbs (Assistant Research Scientist II) will spend 10% of his time overseeing and training staff for task 2a, at a monthly salary $6,508 and benefits rate of 35.7% from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Jr. Specialist II (A) will spend 50% time at a monthly salary rate of $3,082, and benefits rate of 35.7% as estimated for the calendar year 2014-2015 from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Jr. Specialist II (A) will spend 50% time at a monthly salary rate of $3,082, and benefits rate of 35.7% from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Jr. Specialist I (A) will spend 50% of his/her time at a monthly salary rate of $2,890 and a benefits rate of 35.7 from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Undergraduate Lab Assistants we will employee 4 undergraduate students for a max of 10hrs/ week or 25% time @ $9.00/Hr. and a benefits rate of 1.3% from January 1, 2014 to December 31, 2014.

<u>Task 2b: Otolith and Water Geochemistry</u>

Task description: To conduct otolith age, growth and microchemistry to determine natal tributary origin for adult and larval longfin smelt and determine migration history/salinity history of adult longfin smelt (estuarine or ocean life-history of adults).

<u>Staff</u>

Lead Scientist Dr. James Hobbs (Assistant Research Scientist II) will spend 10% of his time overseeing and training staff for task 2b, at a monthly salary $6,508 and benefits rate of 35.7% from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Graduate Student Researcher II will spend 50% time during the 9 month academic year and 100% time during the summer 3 months on task2b at monthly salary of $3,059 (100% time) and an annual health insurance benefit rate of $2,994.

Jr. Specialist II (C) will spend 100% time at a monthly salary rate of $3,082, and benefits rate of 35.7% from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Undergraduate Lab Assistants we will employee 4 undergraduate students for a max of 10hrs/ week or 25% time @ $9.00/Hr. and a benefits rate of 1.3% from January 1, 2014 to December 31, 2014.

<u>Task 3. Project management and reporting</u>

Task description: This task includes the training of all employees, performance evaluation and conducting frequent quality control of data. Tasks will also include quarterly reports to the sponsor, and annual reporting of data and research findings, including oral presentations to the sponsor and local scientific meetings and conferences.

Lead Scientist Dr. James Hobbs (Assistant Research Scientist II) will spend 10% of his time overseeing and training staff for task 3, at a monthly salary $6,508 and benefits rate of 35.7% from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Staff Research Associate II, will spend 25% time at a monthly rate of $3,562, and a benefits rate of 0.51% as estimated for the calendar year 2014-2015 from January 1, 2014 to December 31, 2014. *Note benefit rates may increase at the fiscal year July 1 2014- May 31, 2015.*

Travel

Task 1: Field Sampling (UCD Field Labor, Adult and Larval Longfin Smelt Sampling)

Travel rates include mileage costs for vehicles, boat gas and maintenance during field excursions, not routine maintenance during non-operation hours. Travel includes lodging and food for 4-6 people per site per month, with lodging occurring at distant sites, including Alameda Creek, Coyote Creek and the Petaluma River. We do not anticipate lodging for Sonoma Creek and the Napa River, unless surveys are conducted sequentially and travel back to UC Davis does not result in added cost savings or is deemed unsafe given the work hours on the water,travel times, traffic, and overall safety of the field crew.

Task 3. Project management and reporting

This task includes travel to local meetings including mileage reimbursement and registration for conferences including the Interagency Ecological Program annual meeting and the California-Nevada Chapter of the American Fisheries Society.

Supplies and Expenses

Task 1: Field Sampling (UCD Field Labor, Adult and Larval Longfin Smelt Sampling)

Supplies for field work include UC Davis fleet vehicle rentals for field work. UC Davis policy charges fleet rentals as supplies and not as travel. Field gear includes a replica of the California Department of Fish and Wildlife Egg and Larval Survey net, additional 0.5 meter plankton nets and a hydraulic winch for towing and retrieving gear. Funds for replacement parts on small boat motor, including purchases of parts less than $5,000. Routine scheduled maintenance to be performed by certified boat mechanics. Funds for water quality monitoring equipment including a YSI 6600 or Hydrolab with probes, calibrations materials. Boat gas is also included as a supply expense.

Task 2a: Larval Fish Sorting (This budget is for UCD to do the processing)

Supplies for lab processing of plankton samples for larval fish removal, storage and identification to species. Supplies costs include lab space rental in the Center for Watershed Sciences, where snorkel hood systems have been installed for desktop sorting of formaldehyde preserved contents, stereo dissecting microscope rentals from the UC Davis microscope services facility, and the disposal of waste ETOH and formaldehyde with UC Davis Environmental Health Services (EH&S).

Contingency costs for larval fish sorting, enumeration and identification will be as a sub-contract to Tenera and Associates to perform the task at a cost of $1,000 per sample. We provide a minimum sample size to a total estimate, however the costs are likely to be higher given the pilot scale of the sampling to be done.

Task 2b: Otolith and Water Geochemistry

Costs include recharge rates for the use of Laser Ablation Multi-collector ICPMS at the Center for ICPMS at UC Davis (http://icpms.ucdavis.edu/rates.htm) @ $62/hr. for laser time, plus water sample analyses @ $127/sample. Lab supplies include microscope slides, otolith polishing supplies and compound microscope rentals (*different type of microscope than task 2a*) and a new otolith polishing machine.

Equipment

Task 1: Field Sampling (UCD Field Labor, Adult and Larval Longfin Smelt Sampling)

Description: Costs include replacement of our current boat, a 26-Ft Bayrunner purchased in 1994 by Dr. Peter Moyle with IEP funds for the Suisun Marsh Project. This boat in now almost 20 years old and has extensive hull damage including many small pinholes from years of electrolysis damage and a hole underneath the center console approximately 5-cm in diameter. The boat currently is in operable condition; however the integrity of the hull could be compromised at any point and the boat would no longer be salvageable. Funds requested under equipment would be used to replace this boat if such an event were to occur, thus we include the costs as a contingent to the initial pilot year study plan.

Replacement for 26-Ft Klamath boat (see figure G). We have estimated the cost of a replacement hull to be $70,000 including tax, licensing and registration fees, depending on the specific make and model chosen. The boat would need to be custom designed to include a decking to go over the motor(s) to keep nets from getting tangled in the prop and include hydraulic winches to operate the nets. We would also need to replace the trailer and much of the navigation and communications on the boat. These costs, plus fabrication costs, are estimated to be an additional $30,000. We would replace our current motor with two twin Yamaha 115 hp motors. Duel motor systems would provide us with the necessary torque to pull the egg and larval survey net sled. In addition a second motor would provide us with the extra safety of having a second motor in case a motor goes out while on the water. Several of the study sites are far from boat launches and in the case of Alameda Creek the closest access is greater than 10 miles and on the other side of South Bay. Crossing South Bay in the winter is extremely dangerous, and the added safety of a second motor is important for the safety of the crew. Two Yamaha 115 hp motors would cost approximately $23,000 dollars, plus we would need to upgrade the steering system and transom to handle the weight of two motors. This brings the total for replacing the existing boat and motor to $127,000.

Overhead

The current State overhead rate is 25%, but is subject to increase at the discretion of the governor. Overhead would be to modified total direct cost, which would not include equipment costs, which constitute any product with a retail cost exceeding $5,000, or requiring DMV registration.

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Tables 1-2: Attached.

Principal Investigator and Affiliation:

James Hobbs, Ph.D., ***Research scientist III in the Wildlife Fish and Conservation Biology Department and consulting research affiliate with the Interdisciplinary Center for Inductively Coupled Plasma Mass Spectrometry at UC Davis***.

Dr. Hobbs completed his PhD. in Ecology from the University of California, Davis under the mentorship of Dr. Peter Moyle and was a Sea Grant-CALFED Post-Doctoral Fellow at the University of California, Berkeley under Dr. Lynn Ingram. His research focuses on several elements of fish conservation, restoration and population dynamics. He is a leader in the development of otolith microstructure and microchemistry techniques to understand the population biology and ecology of commercially important and threatened species. Dr. Hobbs has published several articles in peer review literature regarding the application of laser ablation inductively coupled plasma mass spectrometry. Dr. Hobbs has been conducting research in San Francisco Bay for over 15 years focusing on native fish ecology and population biology for conservation and restoration efforts. His recent research focuses on the interdependence of fish life history and healthy habitats, such as the interplay of habitat characteristics of the north Delta and the residency of Delta Smelt in freshwater year round. He is currently leading the monitoring of restored salt ponds in South San Francisco Bay and defining the habitat features that result in the restoration of habitats for native fish, including the Longfin Smelt.

Longfin Smelt Study Plan Timeline

Table 1. Longfin Smelt study timeline. Lead persons for each set of tasks will discuss methods and results with the Longfin Smelt Technical Team. Methods and analyses for future years as needed based on those discussions. Data analysis for Element 3 could show that gear efficiency effects are too small to warrant field study in which case this element would be discontinued. Questions marks indicate uncertainty as to whether sampling will be needed or if reports will be available, depending on when sampling is completed. For example, sampling in Year 4 may only be necessary in order to collect data on age 1+ fish from a cohort sampled in a previous year (e.g., if Year 3 is the only wet year in the dataset, it will be necessary to sample in fall of Year 4 in order to collect data on Age 1+ fish spawned in Year 3). Final reporting tasks will follow the final sampling task by 3-6 months.

		Year 1			**Year 2**			**Year 3**			**Year 4**			**Year 5**	
Study Elements	**Leads**	Winter-Spring	Summer	Fall	Winter-Spring	Summer	Fall	Winter-Spring	Summer	Fall	Winter-Spring	Summer	Fall	Winter-Spring	Summer
1. Lower Bay Spawning Tribuary Use (Study Questions 1 - 5)	**James Hobbs**														
Larva and Adult Tributary Sampling		pending contract			x			x							
Water Chemistry		pending contract			if needed			if needed							
Juvenile and Adult Bay Sampling				x			x			x			x?		
Prelim Summary of Methods & Results				x			x			x			x?		
Final Report -- Addressing Hypotheses												x?	x?		x
2. Larva Production in Napa River (Study Questions 1-5)	**Robert Fujimura**														
Extension of Smelt Larva Survey		pending contract			x			x			x?				
Gear Efficiency Comparison		pending contract			x			x			x?				
Prelim Summary of Methods & Results															
Final Report -- Addressing Hypotheses													x		
3. Longfin Smelt Nearshore Ocean Rearing (Study Question 6)	**James Hobbs**														
Otolith analyses								pending contract	x						
Water Chemistry?								pending contract	x						
Prelim Summary of Methods & Results										x					
Final Report -- Addressing Hypotheses												x			
4. Longfin Smelt Vertical Migration Behavior (Study Questions 7-8)	**David Fullerton, Chuck Hanson**														
Bay Study MWT/OT data analyses		x	x												
Refined Study Questions & Study Design			x												
Design and Take Proposal to IEP MT			x												

Longfin Smelt Study Plan Timeline

		Year 1			Year 2			Year 3			Year 4			Year 5	
Study Elements	**Leads**	Winter-Spring	Summer	Fall	Winter-Spring	Summer	Fall	Winter-Spring	Summer	Fall	Winter-Spring	Summer	Fall	Winter-Spring	Summer
Task 4 (cont'd)															
Field Sampling						pending contract	x?		x?	x?		x?	x?		
Final Report -- Addressing Hypotheses											x?				x
5. IEP Project Workteam and Technical Team Formation and Discussion	**All Pis**														
Formation		x?	x												
Field and Lab Data Review & Discussion			x	x		x	x		x	x	x	x	x		
Report Review				x			x			x			x		x

Longfin Smelt Studies Budget Summary for Pilot Year 1.

	UC DAVIS[1] *(No contingencies)*	UC DAVIS[1] (*with equipment and sub-contracting contingencies)*	California Department of Fish & Wildlife	IEP in-kind contribution (*all tasks)*	Grand Total
Bay Tributary Sampling, Otolith Geochemistry	$ 610,338	$ 784,439			
Napa River Sampling			$ 80,623		
Study Coordination and Management (*IEP in-kind)*				$ 77,000	
			Grand Total *(No UCD contingencies)*		***$ 767,961***
			Grand Total *(with UCD contingencies)*		***$ 942,062***

Table 2a. UC Davis budget for Year 1 (initial pilot year). Costs in subsequent years could increase or decrease depending on findings from Year 1.

TASK 1: Field Sampling (*UCD Field Labor, Adult and Larval Longfin Smelt Sampling*)

CONTINGENCY PLANS

a. personel + fringe

	Annual Base						*No Change*
Hobbs Lab	**FTE**	**FTE-Hours/mo**	**Base salary**	**Salary**	**Benefits**	**Dec-Mar (monthly)**	**Dec-Mar (monthly)**
P.I. Hobbs	10%	16	$ 78,100.00	$ 7,810.00	$ 2,788.17	$ 10,598.17	$ 10,598.17
JS I (A)	50%	80	$ 34,680.00	$ 17,340.00	$ 6,190.38	$ 23,530.38	$ 23,530.38
JS II (A)	50%	80	$ 36,984.00	$ 18,492.00	$ 6,601.64	$ 25,093.64	$ 25,093.64
JS II (B)	50%	80	$ 36,984.00	$ 18,492.00	$ 6,601.64	$ 25,093.64	$ 25,093.64
SRA II	25%	40	$ 42,744.00	$ 10,686.00	$ 5,449.86	$ 16,135.86	$ 16,135.86
Undergraduates1	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	$ 365.40
Undergraduates2	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	$ 365.40
Undergraduates3	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	$ 365.40
Undergraduates4	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	$ 365.40
						$ 101,913.30	**$ 101,913.30**

b. travel

Vehicle rentals	**Monthly**	**4 Surveys**	**Dec-Mar (monthly)**	**Dec-Mar (monthly)**
Mileage(0.565/mi)	$584	**$ 2,336.00**	**$ 3,504.00**	**$ 3,504.00**
Lodging, food	$2,500	**$ 10,000.00**	**$ 17,500.00**	**$ 17,500.00**
			$ 21,004.00	**$ 21,004.00**

c. supplies and materials

	Monthly	**Total Cost**	**Totals**	**Dec-Mar (monthly)**	**Dec-Mar (monthly)**
Fleet Services Truck Rentals					
3/4 ton Van	$404		$ 1,616.32	$ 1,616.32	$ 1,616.32
1/2 ton truck	$391		$ 1,564.32	$ 1,564.32	$ 1,564.32
Replacement trawl and field gear			$ 10,000.00	$ 10,000.00	$ 10,000.00
Water Sampling Materials, hydrolab and trimble			$ 18,000.00	$ 18,000.00	$ 18,000.00
Boat Maintenance	$1,200		$ 4,800.00	$ 600.00	$ 600.00
Boat Gas	$1,000		$ 4,000.00	$ 1,500.00	$ 1,500.00
				$ 33,280.64	**$ 33,280.64**
			Total Direct Cost Task 1	**$ 156,197.94**	**$ 156,197.94**

d.equipment

For new work boat	Est. Costs
26-FT Klamath Boat	$ 100,000.00
2 Yamaha 115 Hp motors (Twin set-up)	$ 27,000.00
Total Equipment Cost	**$ 127,000.00**

TASK 2a: Larval Fish Sorting (*This budget is for UCD to do the processing*)

Tenera and Associates sub-contract for minium number of plantkon sample analysis, total costs

a. personel + fringe

Hobbs Lab	FTE	FTE-Hours/mo	Base salary (Annual Base)	Salary	Benefits	Dec-Mar (monthly)	Dec-Mar (monthly)
P.I. Hobbs	10%	16	$ 78,100.00	$ 7,810.00	$ 2,788.17	$ 10,598.17	$ 10,958.17
JS II (A)	50%	80	$ 36,984.00	$ 18,492.00	$ 6,601.64	$ 25,093.64	
JS II (B)	50%	80	$ 36,984.00	$ 18,492.00	$ 6,601.64	$ 25,093.64	
JS I (A)	50%	80	$ 34,680.00	$ 17,340.00	$ 6,190.38	$ 23,530.38	
Undergraduates5	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	
Undergraduates6	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	
Undergraduates7	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	
Undergraduates8	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	
						$ 85,777.44	**$ 10,958.17**

c. supplies and materials

Monthly	Total Cost	Totals		Cost per plankton sample
Replacement plankton nets and field gear		$ 5,000.00	$ 5,000.00	$ 1,000.00
Jars		$ 2,500.00	$ 2,500.00	
Formalin, ETOH + waste		$ 5,000.00	$ 5,000.00	
Stereo Dissecting Microscope Rentals		$ 2,000.00	$ 2,000.00	
misc. fume hood space rental gloves, safety equipement,		$ 3,000.00	$ 3,000.00	
			$17,500	**$ 120,000.00**

#samples per si	#Site	Months	Total samples
6	5	4	120
	Total Direct Costs Task 2a	**$103,277.44**	**$ 130,958.17**

TASK 2b: Otolith and Water Geochemistry

(Water Geochemistry performed at the Center for Inductively Coupled Plasma Mass Spectrometry)

a. personel + fringe

Annual Base

Hobbs Lab	FTE	FTE-Hours/mo	Base salary	Salary	Benefits	Totals	Contingency Totals
P.I. Hobbs	10%	16	$ 78,100.00	$ 7,810.00	$ 2,788.17	$ 10,598.17	$ 10,598.17
GSR II	9 mo 50%, 3 mo 100%	1200	$ 36,708.00	$ 22,943.00	$ 2,994.00	$ 25,937.00	$ 25,937.00
JS II (C)	100%	160	$ 36,984.00	$ 36,984.00	$ 13,203.29	$ 50,187.29	$ 50,187.29
Undergraduates9	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	$ 365.40
Undergraduates10	25%	40	$9	$ 360.00	$ 5.40	$ 365.40	$ 365.40
						$ 87,453.26	**$ 87,453.26**

c. supplies and materials

Analyses at ICPMS and other chemistry labs			Totals	Oct-Mar (monthly)	Contingency Totals
Water chemistry analysis	$127/sample	45/samples	$ 5,715.00	$ 5,715.00	$ 5,715.00
Laser ablation otolith analysis (trace elements)			$ 10,000.00	$ 10,000.00	$ 1,000.00
Laser ablation otolith analysis (strontium isotopes)			$ 15,000.00	$ 15,000.00	$ 1,500.00
Otolith stable isotope analysis (Oxygen, Sulfur, Carbon etc.)					$ 10,000.00
Microscope slides, polishing materials and polishing wheel			$ 8,000.00	$ 8,000.00	$ 8,000.00
Compound Microscope Rentals (different micscopes than task 2a)			$ 1,500.00	$ 500.00	$ 500.00
				$39,215	**$ 49,215.00**
			Total Direct Costs Task 2b	**$ 126,668.26**	**$ 136,668.26**

d. other

Graduate student fees	*note graduate student tuition does not accrue overhead*	Indirect costs taks 2b	**$ 13,109.00**	**$ 13,109.00**

TASK 3: Project Management and Reporting

a. personel + fringe

Annual Base

Hobbs Lab	FTE	FTE-Hours/mo	Base salary	Salary	Benefits	Annual	Annual
P.I. Hobbs	20%	32	$ 78,100.00	$ 15,620.00	$ 5,576.34	$ 21,196.34	$ 21,196.34
SRA II	25%	40	$ 42,744.00	$ 42,744.00	$ 21,799.44	$ 64,543.44	$ 64,543.44
						$ 85,739.78	**$ 85,739.78**

b. travel

Vehicle rentals	Monthly	4 Surveys	Dec-Mar (monthly)	Dec-Mar (monthly)
local meeting and conferences			$ 500.00	$ 500.00
conference registrations (includes key staff and students = 12 people; IEP meeting and Cal-Neva AFS conference)			$ 5,400.00	$ 5,400.00
			$ 5,900.00	$ 5,900.00

Longfin Smelt Study Plan: UCD Budget (Pilot Year 1)

Total Direct Cost	**$**	**477,783.41**	**$**	**642,464.15**
Total Cost Per Year	**$**	**477,783.41**	**$**	**642,464.15**
Indirect Cost 2014-2015				
State 25%	**$**	**119,445.85**	**$**	**128,866.04**
Grad student fees	**$**	**13,109.00**	**$**	**13,109.00**
TOTAL DIRECT + INDIRECT				
State 25%	**$**	**610,338.27**	**$**	**784,439.18**

New Napa River SLS Expansion Cost Estimates 10/28/13 ld/rwf

PERSONNEL SERVICES

Position Title	Incumbent	Tier	Position #	PY's	Salary	13/14	14/15*	15/16**
						2350 New PCA		
Senior Env Scientist (Sup)	Fujimura	1		0.1	$81,300	$8,130	$8,333	$8,496
Environmental Scientists	Damon/Adib-Samii	1	Various	0.1	$70,584	$7,058	$7,235	$7,376
Mate	Various	1	Various	0.05	$49,440	$2,472	$2,534	$2,583
Senior Lab Assistants	Various	1	Various	0.15	$37,464	$5,620	$5,760	$5,872
Salary and Wages				0.4		$23,280	$23,862	$24,328
Salary Savings						$0	$0	$0
Net Salary & Wages						**$23,280**	**$23,862**	**$24,328**
Temp Help						$6,183	$6,338	$6,461
Overtime						$1,000	$1,000	$1,000
Staff Benefits	T1		0.3733			$8,690	$8,908	$9,081
	Temp Help		0.3733			$3,244	$2,366	$2,412
TOTAL PERSONNEL SERVICES						**$42,398**	**$42,473**	**$43,282**
OPERATIONS EXPENSES* **								
General Expenses						$640	$653	$666
Travel						$520	$530	$541
Training						$400	$408	$416

Rent/Facilities Cost		$5,600	$5,712	$5,826
Communication		$445	$454	$463
Minor Equipment		$1,630	$1,663	$1,696
Nets/Seines		$2,900	$2,958	$3,017
Vehicle Operations		$2,374	$2,421	$2,470
Boat Operations		$2,160	$2,203	$2,247
Uniform Allowances		$150	$153	$156
Chemicals		$500	$510	$520
Printing		$120	$122	$125
Computer Support		$330	$337	$343
TOTAL OE&E		**$17,769**	**$18,124**	**$18,487**
TOTAL DIRECT COSTS		**$60,167**	**$60,597**	**$61,769**
*OVERHEAD**** *	0.34	$20,457	$20,603	$21,002
TOTAL EXPENSES		**$80,623**	**$81,201**	**$82,771**
CONTRACT TOTAL				***$244,594***

*Estimated labor agreement increase = +2.5%
**Estimated labor agreement increase = +4.5%
***Estimate cost increase rate = +2.0%/yr
****Overhead is the DFW headquarters administrative costs and fees; these rates will vary each year

Monitoring the Response of Fish Communities to Salt Pond Restoration: Final Report

Principal Investigator Dr. James A. Hobbs

Co-Investigator Dr. Peter Moyle

Fish Community Study; Lead Author- Nicholas Buckmaster

Sentinel Species Health; Lead Author- Dr. James A. Hobbs

Prepared for

South Bay Salt Pond Restoration Program

&

Resource Legacy Fund

Organization:	*Regents of the University of California*	**RLF Program**:	*BWAS*
Project Name:	*Monitoring the Response of Fish Assemblages*	**Grant No.**	*2009-0215*
Award Amount:	*$275,965*	**Award Date:**	*6/11/09*

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Photo 8. Young-of-year English sole captured via otter trawl in Alviso Slough. Photo: Matt Young.

Photo 9. Pacific herring captured via otter trawl in Alviso Slough. Photo: Matt Young.

Appendices

Appendix A: Evaluation of Otter Trawling Efficiency

Appendix B: Total fish captured via otter trawl for the duration of the study at the Alviso Marsh Complex and Bair Island and associated restored ponds.

Appendix C: Total number of minutes otter trawled each month in each slough

Appendix D: Total number of fish captured via beach seine in 2012 (since seining was standardized)

Introduction

When the first European explorers arrived in San Francisco Bay in the 16th Century, the intertidal margins of the South, Central, and much of North Bay were covered in expanses of pickleweed (*Salicornia (Sarcocornia) sp.*) and *Spartina* marsh, providing habitat for migratory waterfowl, shorebirds, and fishes. Historically, pickleweed encompassed approximately 300 square miles of marsh, an area the size of New York City. Beginning in the mid 1800's, much of this habitat was reclaimed for agriculture, development and salt production, resulting in a 90% reduction in tidal marsh habitat.

Salt marshes support vast numbers of shorebirds and are home to endangered species such as the California Clapper Rail and the salt marsh harvest mouse, and historically supported feeding grounds for migratory fishes such as salmon, sturgeon, anchovy, and herring. Salt marshes are also the permanent home of the longjaw mudsucker (*Gillichthys mirabilis*), a small gobiid fish that makes its home in high intertidal creeklets amongst the pickleweed. The mudsucker has adapted to the high marsh by developing the ability to breathe air and by producing a moist, sticky slimecoat to protect against desiccation (Todd and Ebeling 1966). The longjaw mudsucker is found exclusively within these pickleweed marshes and thus have experienced significant habitat loss within San Francisco Bay/Estuary, much like the endangered Clapper Rail and salt marsh harvest mouse.

In 2003, a consortium of state and federal agencies purchased over 15,000 acres of salt ponds from the Cargill, Inc, and began the largest tidal marsh restoration project west of the Mississippi River. The restoration of these former salt-producing ponds to tidal wetlands presumably would benefit shorebirds, waterfowl, and fish populations. To maximize the benefit to a diverse community, the "restoration" of former production salt ponds has taken several forms, each with different management objectives: full breaching of pond levees to tidal flow to create tidal wetlands; "partial breaching" and the placement of a water control structure to create ponds with muted tides for shorebirds and migratory waterfowl; and ponds that have water levels managed by water control structures that create deeper pond habitats for diving ducks. The creation of a mosaic of habitats utilized of existing pond configurations and maximizes the creation of key habitats outlined in the Goals Project (1999). Moreover, restoration actions that provide operational control of water levels afford the application of adaptive management.

Following the acquisition of the former salt ponds, the ponds on Station Island in the Alviso Marsh (formerly A19-21) were breached under the leadership of the Santa Clara Valley Water District in July 2006. More directed restorations began in 2008 with the initiation of the first phase of the South Bay Salt Pond Restoration Program. Phase One consisted of the full restoration of tidal flow to Knapp's Tract (i.e., Pond A6) in the Alviso Marsh (October 2010), to Outer Bair Island (June 2008), and to ponds E9, E8, and E8x within the Eden Landing Complex (November 2011). In addition, Pond SF2 (Ravenswood) was fitted with a water control structure and limited tidal flows were restored to the pond, and Pond A8 was fitted with a tide gate and connected to Alviso Slough during summer months in an attempt to flush out high concentrations of mercury that had accumulated within the sediments.

The goal of this project is to document the species assemblages within the restored salt ponds and to design a monitoring program to assess the effect of pond restoration on fish assemblages inside newly breached ponds and adjacent sloughs.

Fish Community Study

Study Areas

South San Francisco Bay (referred to hereafter as "South Bay") is a tectonically formed embayment along the southeastern leg of the San Francisco Bay Estuary (Atwater 1979). This basin has a wetted area of 554 square kilometers (km^2) and a mean depth of 3.4 meters (m) at mean low water (Cheng and Gartner 1985). South Bay consists of mostly open-water and sandy- and muddy-bottomed habitat that is bordered by several remnant marsh complexes and active salt ponds owned by Cargill, Inc. Some of these marshes have been or are in the process of being restored to tidal action for the benefit of a suite of biota.

Unlike the northern portions of the San Francisco Estuary, there is not a delay in high tide as you move away from the Golden Gate, but rather tides move as a standing waves, resulting in the near simultaneous occurrence of high slack tides throughout the southern portion of the basin (Cheng and Gartner 1985). In addition, the two principle tidal force components become increasingly out of phase, which, in addition to a decrease in the mean basin depth, results in an increased tidal amplitude in the southern part of the bay (i.e., the Alviso Marsh Complex) (Cheng and Gartner 1985).

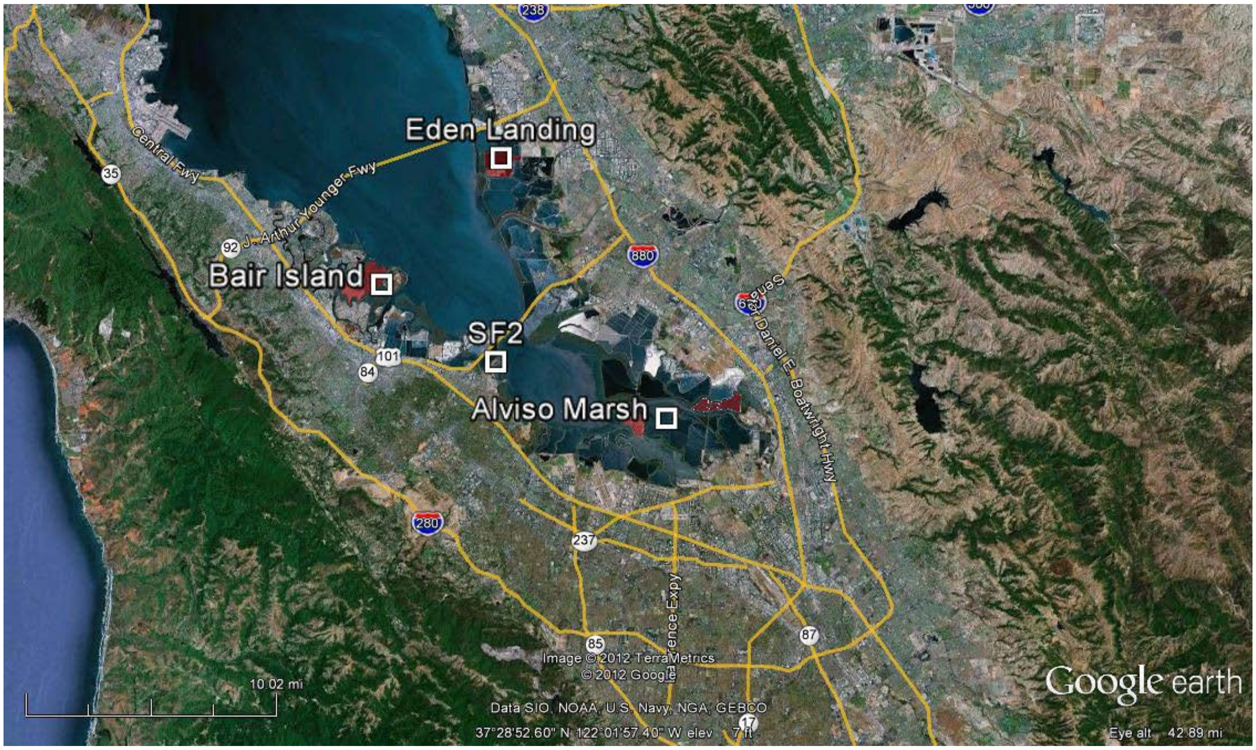


Figure 1. Marsh complexes under study.

Alviso Marsh Complex

The Alviso Marsh Complex is the southernmost marsh of South Bay and is the location of the earliest restoration actions by the South Bay Salt Pond Restoration Program. The Alviso Marsh Complex consists of two major tidal channels and four tributary sloughs (Figure 2a). Alviso Slough is fed by the Guadalupe River at the uppermost end, is shallow (<4-m depth), is relatively narrow (30- to 70-m wide), and is bordered by earthen levees along much of its 8-km length. Alviso Slough contains the Port of Alviso, the home of a small commercial fishing fleet and the Alviso Marina. Alviso Slough has a small brackish marsh (~0.1 km^2) dominated by bulrush (*Schoenoplectus* sp.) located at the Alviso County Park, which is immediately downstream of the port. Alviso Slough is adjacent to Knapp's Tract at its lower end, and two of the Knapp's Tract breaches drain into the slough. The lower 5 km of slough are bordered by marshes dominated by cordgrass (*Spartina* spp.) and pickleweed (*Sarcocornia* spp.).

Figure 2a. Alviso Marsh Complex and sloughs. Breached ponds are shaded red.

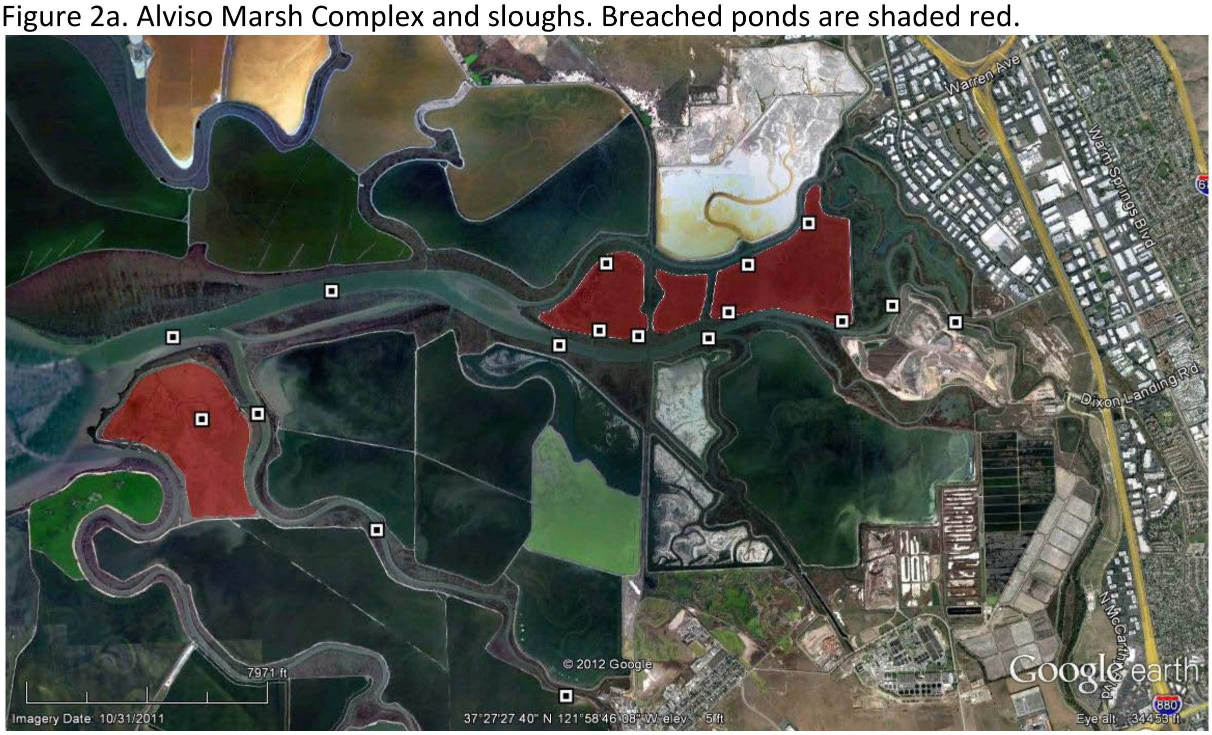


Figure 2b. Otter trawl sampling stations in Alviso Marsh Complex.

Coyote Creek is fed by Coyote Creek at the upstream end and empties into South Bay at its downstream end. Coyote Creek is bordered by the initial restoration areas (Island Ponds), is bordered by the brackish Warm Springs Marsh, and has four tributary sloughs draining into it: Alviso Slough, Mud Slough, Artesian Slough, and Abrae. Coyote Creek (the largest slough in the Alviso Marsh Complex) is ~11-km long, is 65-m wide at its upstream end, is 100-m wide adjacent to Pond A21, and 375-m wide at its lower end; it has maximum depths that range from 5 m (adjacent to South Bay) to 2 m at its uppermost end. Like Alviso Slough, Coyote Creek is bordered by earthen levees, with a narrow band of cordgrass- and pickleweed-fringing marsh along the lower 9 km; however, directly across from Pond A21, Coyote Creek is bordered by the historic Triangle Marsh, a salt marsh about the size of the smallest Pond A21(~0.3 km^2) (Stevenson et al. 1987).

Artesian Slough is the third-largest slough within the Alviso Marsh Complex and is the location of the Santa Clara/San Jose Wastewater Treatment Center, which discharges tertiary treated sewage into Artesian Slough.

There are four fully tidal, restored salt ponds within the Alviso Marsh Complex. In order of increasing wetted area, they are A20, A21, A19, and A6 (Knapp's Tract). All four ponds are ringed by earthen levees, though the levee in A6 has been lowered to facilitate tidal exchange. A19, A20, and A21 (referred to collectively as the "Island Ponds") are located on Station Island adjacent to the former town of Drawbridge and are mostly intertidal. All three are ringed by a "borrow ditch" (so called because the ditch was created by borrowing pond sediment to construct the levees). The borrow ditch is typically 1-2 m lower than the former salt pan, which is the relatively flat surface used to evaporate salt. The borrow ditches get considerably shallower as you move away from the breach. The salt pan on A21 is the highest in elevation and is the most heavily vegetated of the Island Ponds. A19 has the lowest salt pan and has the least amount of vegetation (Fulfrost 2011). A6 was modified prior to breaching, and the former borrow ditch quickly accreted sediment (personal observation). The former salt pan of A6 has begun to vegetate, but coverage is less than 20% that of A21 (Fulfrost 2011). Unvegetated intertidal salt pans support large amounts of green algae in the spring and summer months, which likely provide easily accessible organic material for primary consumers.

Photo 1. Marsh plain of A19 (top) with very little vegetation and A21 (bottom) with considerable amounts of vegetation.

Bair Island Marsh Complex

The Bair Island Marsh Complex is adjacent to the Port of Redwood City. Bair Island consists of three islands (inner, middle, and outer) separated by tidal sloughs. The Bair Island salt ponds were abandoned in the 1970's after less than two decades of salt production (Phillip Williams and Associates, 2000). The central outer pond (Figure 3) was passively recolonized by marsh vegetation and was allowed to return to tidal salt marsh, while the southernmost outer pond was used to deposit supra-tidal dredged material from the adjacent port (Bair Island Restoration and Management Plan appendix A 2000). The vegetation community of Bair Island largely consists of pickleweed and cordgrass. The northernmost pond in outer Bair Island was breached in 2008 and has begun to recruit pickleweed and cordgrass to the marsh surface. The intertidal ponds in outer Bair Island are ringed by a borrow ditch, similar to those at Alviso.

Figure 3a. Bair Island Marsh Complex and adjacent sloughs. Breached ponds are shaded red.

Figure 3b. Otter trawl stations within the Bair Island Marsh Complex.

The sloughs surrounding Bair Island consist of Redwood Creek to the south/southeast, Smith Slough to the south/southwest, Steinberger Slough to the north/northwest, and the central South Bay channel to the east. The Redwood Creek channel is dredged to a depth of about 10 m for shipping. Though the position of the sloughs has not changed since 1857, building of levees and the creation of the Foster City development to the north halved the Steinberger Slough drainage, resulting in a decrease in current velocity and the gradual sedimentation of the slough. Though the slough remains unvegetated, Steinberger Slough and much of Corkscrew Slough are intertidal, with an average depth of ~0.5 m above mean low water (Philip Williams & Associates appendix A 2000). It is likely that the reconnection of former marsh habitat to Steinberger Slough will cause scouring and an increase in average depth. The remnants of earthen levees that were used to construct the salt ponds border Corkscrew, Smith, and Steinberger sloughs; however, Redwood Creek and the adjacent deepwater channel are bounded by mudflat.

Eden Landing

Eden Landing is the site of the oldest commercial salt ponds in San Francisco Bay, and it probably was a salina (a natural salt flat where little or no vegetation occurs) prior to its development in the 1850s (Johnck 2008). The restored Eden Landing Marsh (Figure 4) is bounded on the north by the newly constructed Mt. Eden Creek flood control channel and is bounded on the south by the Old Alameda Creek channel. The lower ends of Mt. Eden Creek and Old Alameda Creek are bounded by riprapped levees, and are bounded by earthen levees with the exception of the pond breaches upstream of the riprapped areas.

Figure 4. Eden Landing Marsh Complex and associated sloughs

Three ponds in Eden Landing were restored to tidal action. The newly breached habitat at Eden Landing has already begun to vegetate, primarily with pickleweed. Eden Landing ponds lack a clearly defined borrow ditch, making them different from the Alviso and Bair Island ponds. The Eden ponds do have some vestigial tidal creeks in some areas that are completely intertidal.

Ravenswood

Ravenswood is a managed pond on the western shore of South Bay, directly below Dumbarton Point. The former salt pond was fitted with water control structures, and the water level is managed to facilitate foraging of shorebirds. Because of the limited tidal range within the pond, very little vegetation has recruited within the pond complex. Ravenswood is adjacent to a fringing salt marsh dominated by pickleweend and gumplant (*Grindelia*). The fringing marsh is between 100-m and 30-m wide and has several 2^{nd} and 3^{rd} order creeklets (small, typically dendritic tidal channels) draining it. The channel that connects the water control structures to the adjacent bay cuts through the marsh and is about 20-m wide and 60-m long. Because of the limited tidal flow, there is poor channel definition within the pond itself, but the remnant borrow ditch is present.

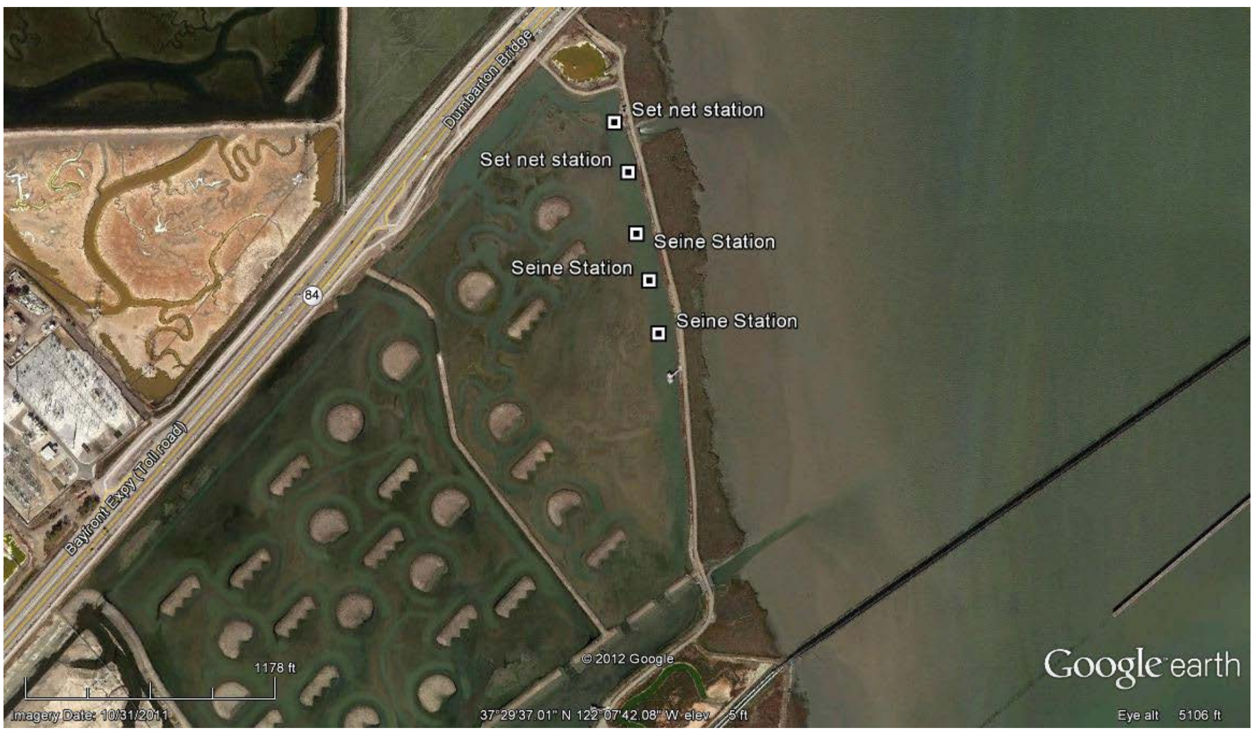


Figure 5. Ravenswood (SF2) and sampling stations.

Sampling Methods

Beginning in July 2010, we began sampling sites within the Alviso, Eden Landing, and Bair Island marshes. Initial sampling trips consisted of otter-trawl surveys in the slough habitats and the deployment of 10-15 baited minnow traps in intertidal creeks on the marsh plain; however, prior to October 2010, no otter trawls were used at Eden Landing. Beginning in October 2010, we began sampling at Ravenswood Marsh using minnow traps and a modified beam trawl. By May 2011, we modified our sampling techniques to maximize safety and improve sampling efficiency.

From July 2010 to May 2011, bimonthly juvenile and adult fish sampling was conducted at standard sites within the Alviso Marsh Complex and the Bair Island Marsh using a four-seam otter trawl with a 1.5 m X 4.3m opening, a length of 5.3 m, and a mesh size of 35-mm stretch in the body and 6-mm stretch in the cod end. Prior to May 2011, between 14 and 20 otter trawls were conducted within the Alviso Marsh Complex, and six to 12 trawls were conducted at Bair Island. Beginning in May 2011, 15 stations were sampled monthly within the Alviso Marsh Complex, with those adjacent to Station Island being sampled twice each sampling trip at high and low tide. Stations were located along Coyote Creek and along Alviso Slough. Two tributary sloughs (Artesian and Mud) to Coyote Creek were sampled over part of this study; however, sampling was intermittent and the stations were eventually abandoned in May 2011. Beginning in July 2011, five stations were sampled at Bair Island using the otter trawl. Otter trawl surveys at Bair Island were expanded to include four additional sites in order to accommodate recently breached habitat in May 2011, and the frequency of surveys was increased to monthly. Sampling at Eden Landing was sporadic because of seasonal navigation hazards and levee closures during favorable tides. Because of the high elevation of the marsh and an increase in navigational hazards originating from construction in Pond E9, otter trawling was abandoned at Eden Landing in May 2011. Eden Landing was sampled approximately quarterly from June 2011 to June 2012 using baited minnow traps, seines, gillnets, and a smaller, less efficient otter trawl. Trawls were towed for 5 minutes in small sloughs (<3-m deep and <70-m wide) and for 10 minutes in larger sloughs (>3-m deep and >70-m wide) to compensate for small catches. Monthly gillnet and trammel-net (referred to as "set nets") surveys were initiated in May 2011 at both Bair Island and Alviso in an attempt to survey fish species capable of evading trawl surveys. At Pond A6, Alviso Slough adjacent to A6, Pond A8, Eden Landing, and Ravenswood, inshore fishes were sampled using a 30-m, 1.2-m-deep beach seine having a stretched mesh size of 10 mm and a bag size of 1.5 m x 1.5 m. A small four-seam otter trawl with a mouth size of 2.44 m x 0.75 m, a length of 3 m, a mesh size of 32-mm stretch in the body and 6-mm stretch in the cod end was used to augment the seine catches within A6 because depth <1 m precluded the use of larger sampling gear.

For each site, temperature (degrees Celsius, °C), salinity (approximated by practical salinity units, PSU), dissolved oxygen parameters (percent saturation, and milligrams per liter, mg/L), and specific conductance (microSiemens, µS) were recorded using a Yellowstone Springs Instruments (YSI) model 85 meter. Water clarity was measured using a Secchi disk and recorded in centimeters (cm). Depths at which the trawl was towed were also recorded.


Photo 2. Deploying the large otter trawl.

The contents of each trawl, seine, trammel net, or gillnet were placed into large containers of water. Fishes were identified, measured to the nearest millimeter standard length, and released. Sensitive and native species were processed first and immediately released. Numbers of bay shrimp (*Crangon franciscorum, Crangon nigricauda, Crangon nigromaculata*), Oriental shrimp (*Palaemon macrodactylus*), and bivalve mollusks (e.g., *Corbula amurensis*, *Corbicula fluminea*, and *Macoma* sp.), brachyuran decapods (e.g., *Hemigrapsus oregonensis*, *Metacarcinus magister* (formerly *Cancer magister*)) were also recorded. Crustaceans from the order Mysida were pooled into one category, “mysids,” and given and abundance ranking: 1 = 1-3 mysids, 2 = 4-50 mysids, 3 = 51-100 mysids, 4 = 101-500 mysids, and 5 = >500 mysids. High numbers of mysids within the restoration areas made the index necessary because otter trawls are not an efficient way to sample mysids, and those that are captured are very difficult to count. A similar index was developed for crustaceans from the order Isopoda: 1 = 1-3 isopods, 2 = 4-10 isopods, 3 = 11-50 isopods, 4 = 51-100 isopods, and 5 = >100 isopods.

Because of an equipment malfunction, no sampling was conducted in February 2012; however, Alviso and Bair Island were sampled in late January and again in early March in an attempt to mitigate the issue.

Data Analysis

Species accumulation curves were used to identify the appropriate amount of effort required to document the species assemblages both within the Alviso Marsh Complex and the Bair Island Marsh and within the slough/restoration areas of the marsh. Cumulative effort was plotted against cumulative number of species captured, and the point at which diversity stopped increasing was deemed the appropriate effort for that region.

For this report, catch-per-unit-effort was calculated for individual trawls as

Equation 1: $$\text{CPUE}_{\text{(trawl)}} = \sum_{i=1}^{j} \left(\frac{i}{n}\right) x5$$

where *i*=is the number of fish species "*i*" that were captured, *j* is the total number of species in each trawl and n is the total number of minutes the trawl was towed. Because the shortest trawl that is currently used in this study is five minutes long, CPUE is standardized for 5-minute trawls (i.e., if one fish from species X is captured in a 5-minute tow, the $\text{CPUE}_{\text{(trawl)}}$ trawl for that species is one, if one fish is captured in a 10-minute tow, the $\text{CPUE}_{\text{(trawl)}}$ for that that species is ½).

Monthly and regional CPUE was determined by:

Equation 2: $$\text{CPUE}_{\text{month or region}} = \sum_{n=1}^{n} \frac{(\text{CPUE (trawl)})}{n}$$

where *n* is the number of trawls. Monthly water quality samples were determined by the same formula, with the water quality parameter of interest being substituted for $\text{CPUE}_{\text{trawl}}$ in Equation 2. Gillnet and trammel net CPUE were computed using Equation 1, with the time the net was deployed being substituted for the trawling time.

Frequency of occurrence was calculated by:

Equation 3: $$\text{Frequency of Occurrence}_{(I)} = \frac{p}{n}$$

where *p* is the number of trawls in which fish species *i* is present and *n* is the number of trawls.

Because the field samples are spatially and temporally autocorrelated, they violate parametric assumptions. This makes "replicate" trawls within a habitat pseudoreplicates as they are not independent. Placing error bars on CPUE and frequency-of-occurrence data is therefore inappropriate (Hurlburt 1984).

Sampling frequency for the fish community surveys were determined using a presence/absence, pairwise comparison between sampling events (Sørensen similarity index, or SSI). These comparisons were blocked by marsh (e.g., Alviso Marsh Complex in December was only compared with Alviso Marsh Complex in November). The SSI is given by:

Equation 4: $$QS=\sum_{n=0}^{n}\frac{2n\mathrm{A}\cap\mathrm{B}}{n\mathrm{A}+n\mathrm{B}}=\sum_{n=0}^{n}\frac{2\mathrm{C}}{\mathrm{A}+\mathrm{B}}$$

where *A* and *B* are the number of species in samples A and B, respectively, *C* is the number of species shared by the two samples, and QS is the similarity index. The SSI was also used to compare restored habitat with unrestored habitat.

In addition to the SSI, the Bray-Curtis similarity index was also used to compare sequential sampling trips as well as restored and unrestored habitats. The Bray-Curtis index accounts for the actual abundance of fish species, not just the presence/absence of species.

Equation 5: $$BC=\sum_{n=0}^{n}\frac{Min(\mathrm{A}\cap\mathrm{B})}{n\mathrm{A}+n\mathrm{B}}=\sum_{n=0}^{n}\frac{2*Min(\mathrm{C})}{\mathrm{A}+\mathrm{B}}$$

where *A* and *B* are the number of individuals from all species in samples A and B, respectively, C is the minimum number individuals of species *n* if that species occurs at both sites, and BC is the similarity index.

In order to simplify the discussion, the water quality section will be limited to the two marshes where otter trawling is the principle sampling method employed (the Bair Island Marsh and the Alviso Marsh Complex). The water quality of Bair Island is similar to that at both Eden Landing and outside of the Ravenswood complex (see Hobbs and others 2011).

Water quality parameters for Central South San Francisco Bay were obtained from the US Geological Survey's water quality survey of San Francisco Bay website. Delta outflow was obtained from the California Department of Water Resources' Dayflow website.

Results and Discussion

Environmental Conditions

Salinity

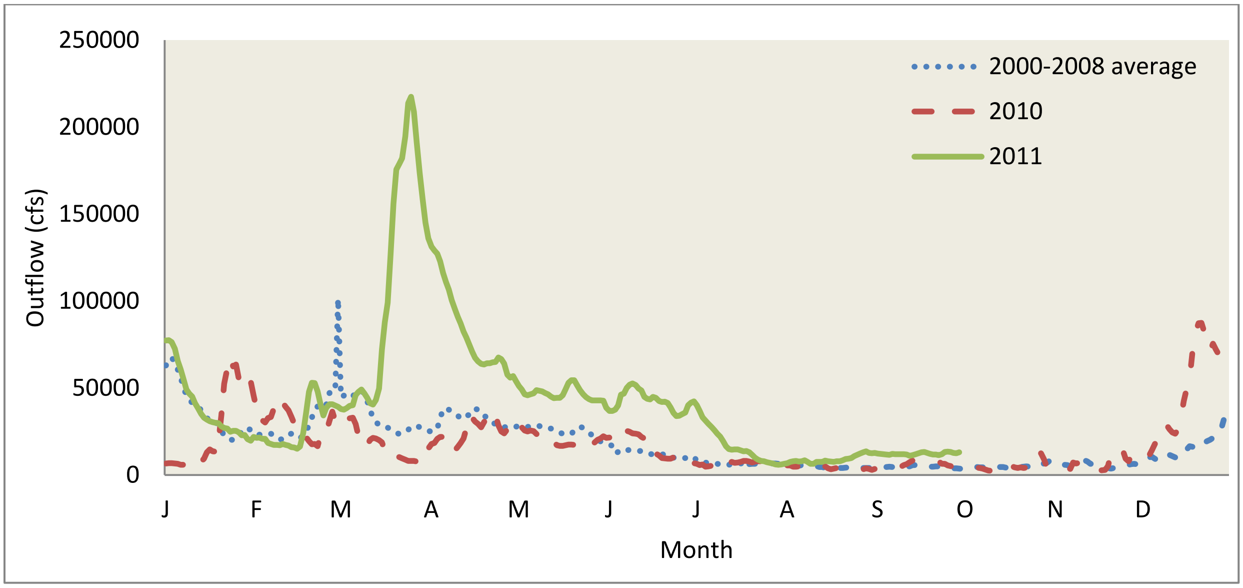


Figure 6. Daily Delta outflow in cubic feet per second (cfs) for 2010, 2011, and the average for the years 2000 - 2008 (Dayflow 2012).

Salinities within South San Francisco Bay are inversely correlated with both Delta outflow and outflow from local creeks (Stevenson et al. 1987), and are typically lowest in the winter and spring months. Historically, Delta outflow explains 85% of the salinity variation in the Alviso Marsh Complex, and local stream flows accounted for 15% of the variation (Stevenson et al. 1987). Reflecting average Delta outflow and local stream runoff, salinities in 2010 were close to average and had already increased to summer highs at the start of this project in July 2010 (Figure 6,7, and 8). In 2011, above-average precipitation in both local watersheds and in the Sacramento-San Joaquin watershed resulted in high Delta outflows and high local stream flows (Figure 6 and 7). This resulted in salinities than were lower than average for a longer time period in 2011 than in either 2010 or 2012 (Figure 7 and 9). Precipitation in all drainages during the 2012 water year has been below average to date and has resulted in salinities that are higher than average.

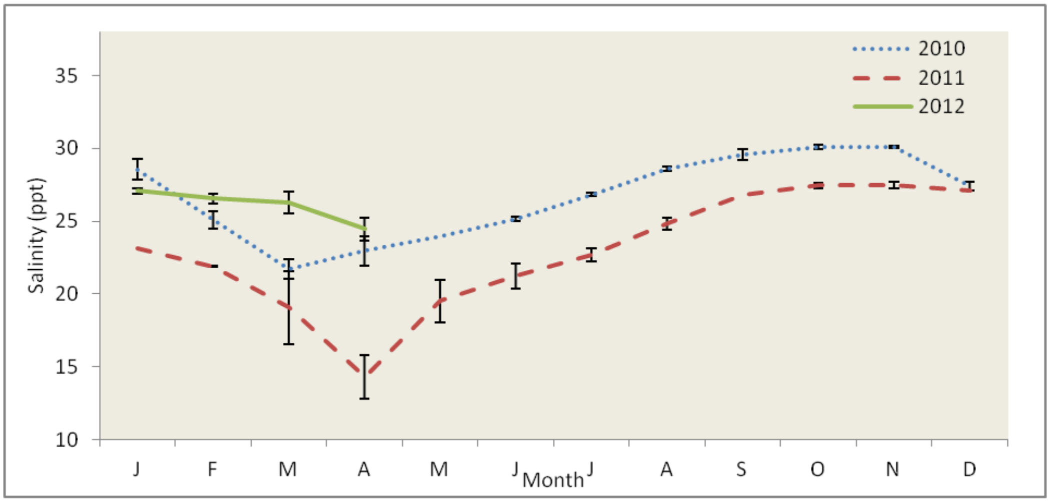


Figure 7. Monthly salinities measured in "central" South San Francisco Bay, adjacent Bair Island (USGS SFB WQ monitoring, accessed July 2012). Error bars are ±1 SD.

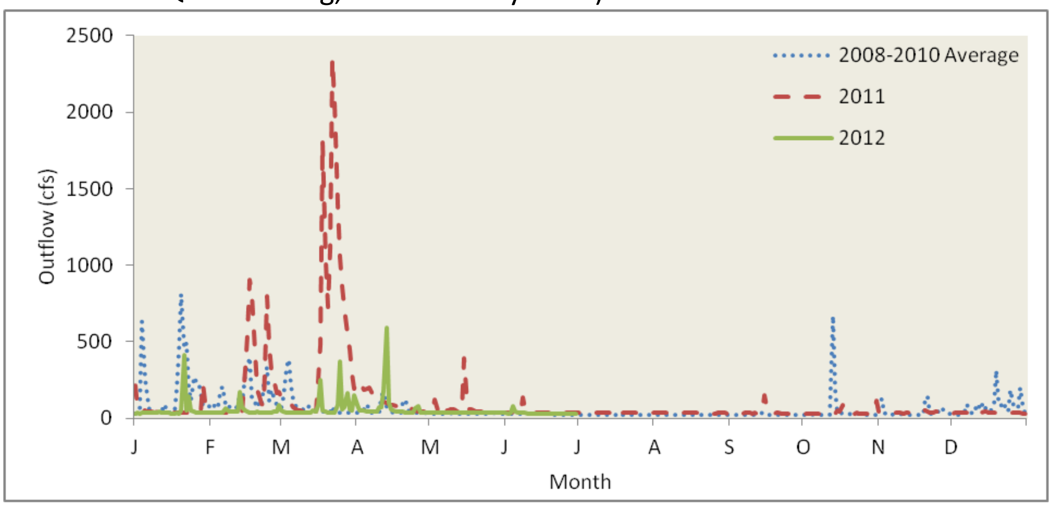


Figure 8a. Daily averages of local stream inflows for the Alviso Marsh Complex from the Guadalupe River.

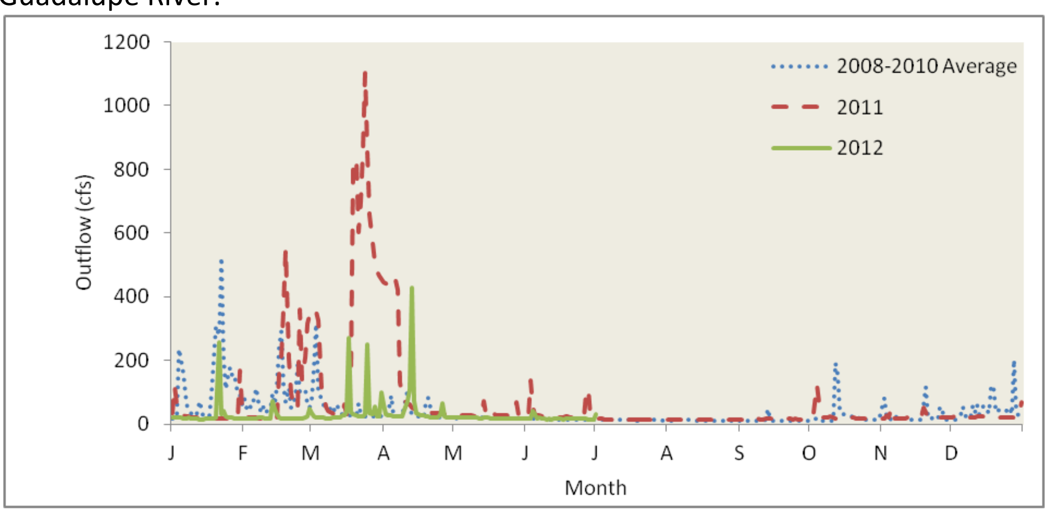


Figure 8b. Daily averages of local stream inflows for the Alviso Marsh Complex from Coyote Creek.

The Alviso Marsh Complex lies downstream of the Guadalupe River and Coyote Creek - two of the three largest tributaries to South San Francisco Bay - and contains the discharge site of the San Jose/Santa Clara wastewater treatment facility, which releases tertiary treated sewage throughout the year at a rate of approximately 200 cubic feet per second (cfs). As a result, this region had lower and more variable salinities than other study sites (Figure 9). There is a distinct geographic gradient in place year-round in the Alviso Marsh Complex, with the lowest salinities consistently located in upper Artesian, upper Alviso, and upper Coyote Creeks and the highest salinities adjacent to South San Francisco Bay. The amplified tidal range in the Alviso Marsh Complex and the perennial input of freshwater from local sources result in salinity swings of over 10 ppt throughout the tide cycle (MacVean and Stacey 2011). These salinity fluctuations likely preclude more stenohaline organisms from all or part of the marsh at certain tides.

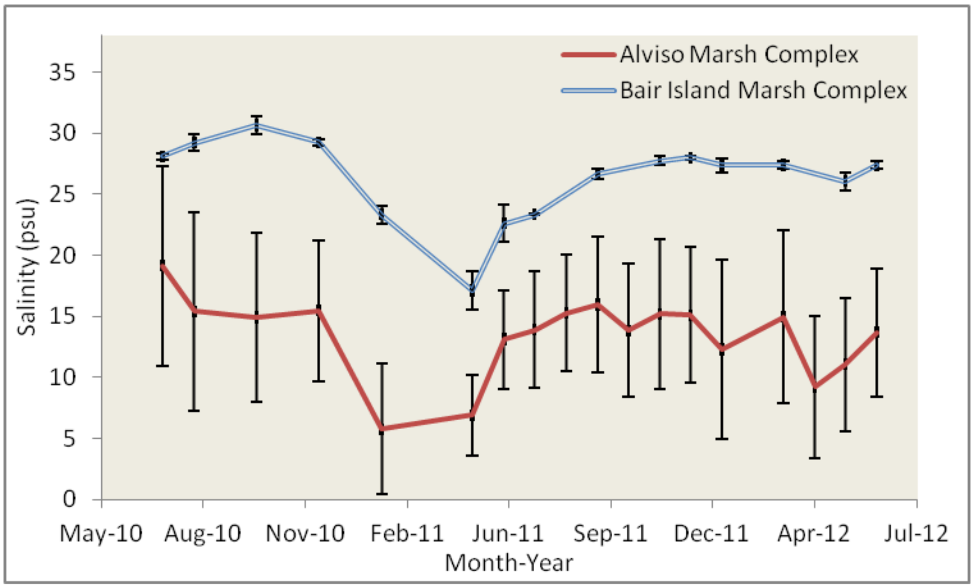


Figure 9. Monthly average salinities within the Bair Island Marsh and within the Alviso Marsh Complex. Error bars are standard deviation for each month.

Bair Island and Ravenswood lack significant freshwater inflow. As a result, these marshes have more stable salinity regimes, both geographically and throughout the tide cycle (Figure 9). Because of these marshes' proximity to the deep water channel of central South Bay, salinities within these marshes tend to be close to the salinities in the adjacent South Bay (Figure 6).

<u>Dissolved Oxygen</u>

Dissolved oxygen (DO) concentrations in salt marshes are typically affected by primary production, decomposition of organic material, salinity, tide regime, nutrient input, and temperature. Typically, DO is the highest in the winter and spring months and lowest in the summer and fall. In early spring, photosynthetically derived oxygen can increase oxygen levels to the point of supersaturation in shallow habitats (e.g., restored salt ponds).

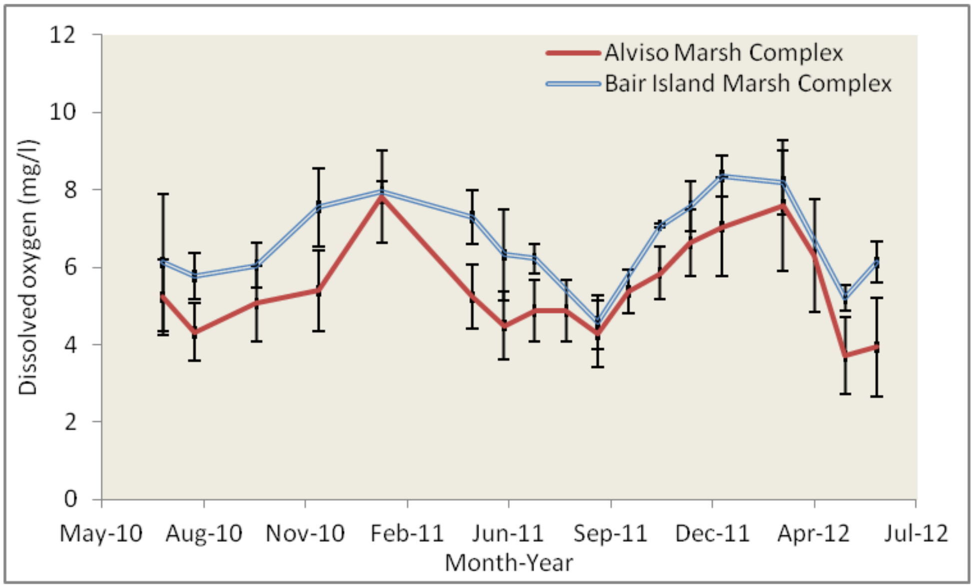


Figure 10. Monthly dissolved oxygen levels at Bair Island Marsh and Alviso Marsh Complex. Error bars are monthly standard deviations.

Nutrient loading of salt marsh habitats has been shown to lead to eutrophication and anoxia in other systems (Deegan 2002). Nutrient levels within South Bay are consistently high, in large part because of the high volume of tertiary treated sewage that is discharged into the basin (USGS SFB Water Quality Monitoring, accessed July 2012). It is apparent that the high nutrient load allows for tremendous algal production within salt-pond habitats, and the subsequent accumulation and decomposition of organic debris within these habitats results in hypoxia (DO levels <30%) in certain areas during the night/early mornings in the summer and fall (S. Poitter, USGS, pers. com, this study).

The monthly average DO in central South Bay showed the expected seasonal patterns but was consistently above 6 ml/L and 80% saturation. The monthly average oxygen concentration within the Bair Island Marsh was more variable over the course of the year and reached lower levels than the adjacent bay. DO concentrations within the Alviso Marsh Complex (Alviso Slough, Coyote Creek, the Island Ponds and Knapp's Tract) were considerably lower than both central South Bay and Bair Island, dropping to levels that are stressful to many fish species at all locations. The Alviso Marsh Complex also had several hypoxic and anoxic (less than 10% saturation) events during our sampling periods: on July 1, 2011, waters with oxygen levels below 1.0 mg/L were observed at the mouth of Pond A19; and on October 20, 2010, storm-water runoff from both Coyote Creek and the Guadalupe River led to hypoxia in upper Alviso Slough and in upper Coyote Creek. Both events resulted in fish mortalities.

Transparency and Temperature

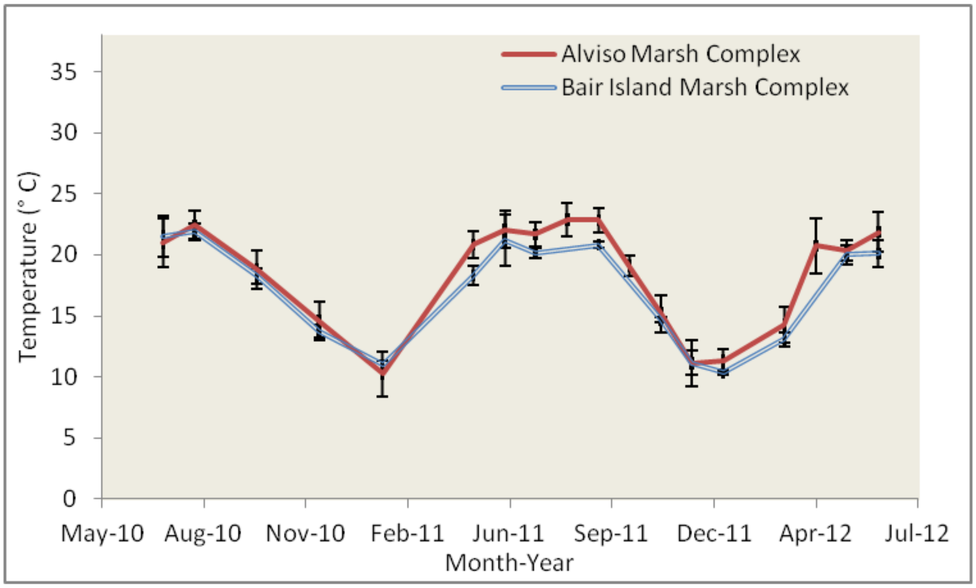


Figure 11. Monthly average temperatures at the Bair Island Marsh and at the Alviso Marsh Complex. Error bars are standard deviation for each month.

Water temperatures in the restoration area exhibit a seasonal pattern: coldest temperatures occur in winter (December to February) and warmest temperatures occur in summer (July and August).

Recorded monthly water temperatures followed the expected seasonal pattern during the course of this study, though several deviations are worth pointing out. First, the 2010/2011 winter was cooler than the 2011/2012. Second, the Alviso Marsh Complex gets consistently warmer in the summer months than the Bair Island Marsh due its shallow depth.

Turbidities can be affected by phytoplankton, total dissolved solids, water speeds, and winds. Overall, turbidity is higher in the southern portion of South Bay, especially below Calaveras Point because increases in tidal energy keep fine sediments in suspension. As a result, turbidities in the Alviso Marsh Complex were consistently high year round (Figure 12). Turbidities within the Bair Island Marsh Complex were typically lowest in the winter months and highest in spring and early summer. Unlike the Alviso Marsh Complex, it is likely that the increased turbidity in the Bair Island Marsh was due to seasonal phytoplankton blooms, which peaked in April of each year (USGS SFB WQ monitoring 2012).

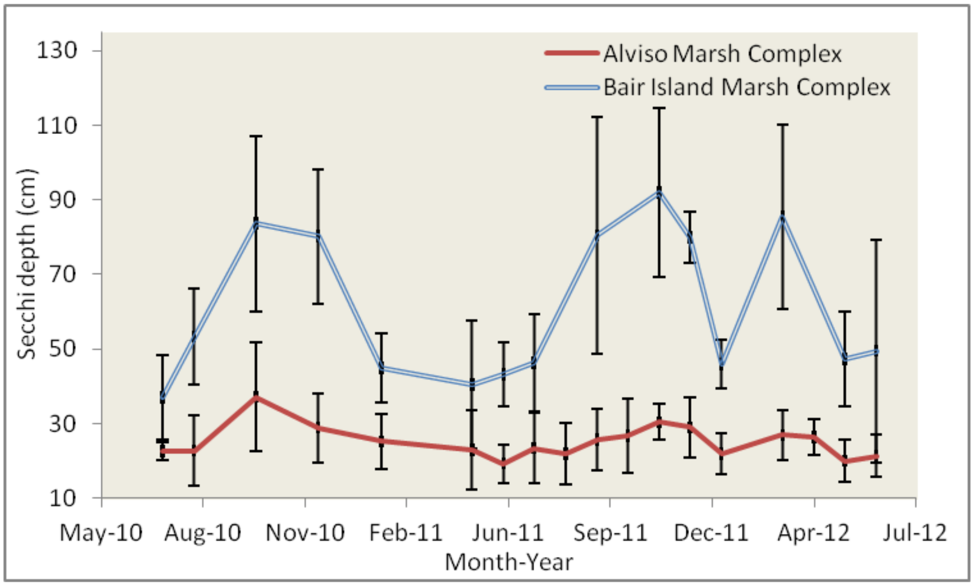


Figure 12. Monthly average transparency from each marsh from July 2010 to June 2012. Error bars are standard deviation for each month.

Invertebrate trends and observations

We have captured 38 species of macroinvertebrates in otter trawling surveys from July 2010 to June 2011. Four planktivores are abundant (California bay shrimp (*Crangon franciscorum*), overbite clam, (*Potamocorbula amurensis*), Oriental shrimp,(*Paleomon macrodactylus*), and black-tailed bay shrimp, (*C. nigricauda*)) in trawl catches, as well as the Oregon mud crab (*Hemigrapsus oregonensis*), the New Zealand opisthobranch (*Philini auriforms*), and the eastern mudsnail (*Ilyanassa obsoleta*). California bay shrimp constituted over 61% of the total individuals captured (excluding isopods and mysids). Of the total species captured, at least 20 (53%) are nonnative to the San Francisco Bay/Estuary; however, only 36% of total individuals captured in otter-trawls were invasive. Overbite clam were introduced into the estuary in the late 1980's and became abundant in 1990. Beginning around 2000, overbite densities began a dramatic decrease in South San Francisco Bay (Cloern et al. 2007), though they are still exceptionally abundant within the Ravenswood Pond and within the Alviso Marsh (this study).

<u>Bay Shrimp</u>

California bay shrimp typically reproduce outside of the Golden Gate and then migrate upstream into the brackish waters of the estuary coincident with salinity incursion in the summer months (Hatfield 1985). Peak abundance in San Francisco Bay/Estuary follows the movement of juvenile shrimp into Suisun and San Pablo Bays and Suisun Marsh in summer months (Hatfield 1985, O'Rear and Moyle 2011). Because sampling began in July 2010, the discussion is broken up into Year 1 (July 2010 to June 2011) and Year 2 (July 2011 to June 2010).

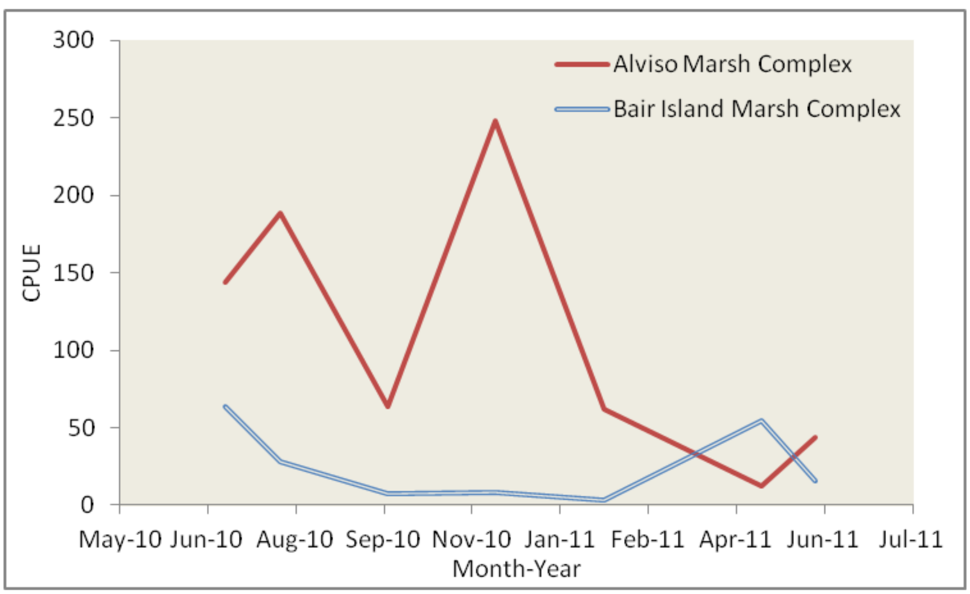


Figure 13. CPUE of bay shrimp from July 2010 to June 2011

Year 1

From July 2010 to June 2011 in the Alviso Marsh Complex, California bay shrimp reached peak abundance in December 2010 and then declined rapidly in the spring months. By June 2011 the arrival of new recruits caused the CPUE of California bay shrimp to increase slightly; however, the catch throughout the marsh was still less than in December. The 2011 cohort never reached high abundance within the Alviso Marsh Complex in this first year, despite lower salinities that attract young shrimp. The apparent paucity of California bay shrimp was possibly caused by the harvest of 24,000 lbs by the local fishing fleet (CA DFG 2011), as the salinities within the Marsh were ideal for young shrimp. At the Bair Island Marsh Complex, the 2010/2011 California bay shrimp CPUE was low during winter months, displayed a peak in May of 2011, and then declined rapidly the following month. It is likely that the bulk of the California bay shrimp observed at Bair Island in May were migrating recruits that rapidly moved out of the area. This hypothesis is corroborated by the arrival of the new recruits in the Alviso Marsh several weeks later. Black-tailed bay shrimp were not particularly abundant in either the Bair Island complex or in the Alviso Marsh during the first year of sampling, presumably due to this species preference for waters in excess of 19 ppt (Wahle 1982). Trends in California bay shrimp catches were similar in both the restored habitats and the adjacent sloughs during the first year of sampling (Figure 14).

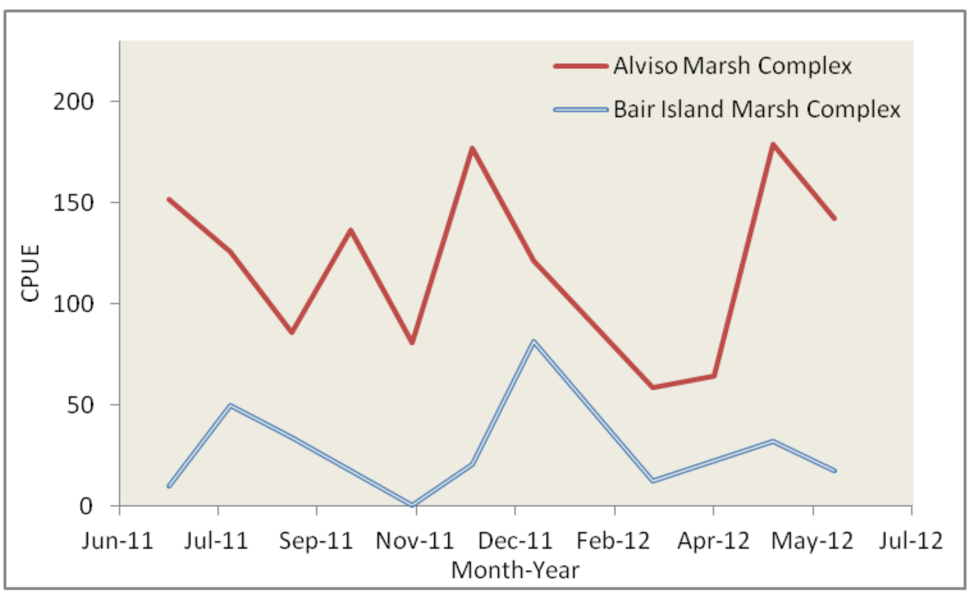


Figure 14. CPUE of bay shrimp from July 2011 to June 2012

Year 2

Overall, California bay shrimp CPUE was higher from August 2011 to June 2012 than from August 2010 to June 2011 (Figure 14). The outmigration of mature adults occurred in March and April 2012 resulted in a decrease in CPUE at both the Alviso and Bair Island Marsh complexes. The recruitment pulse occurred later in 2011 (July) than in 2012 (May), though CPUE of newly recruited bay shrimp in 2012 was comparable to 2011 (Figures 13 and 14). Hatfield (1985) theorizes that in dry years, California bay shrimp may reproduce in South Bay; however, despite the presence of gravid females in the Alviso Marsh from November 2011 to February 2012, no larval or early juvenile bay shrimp were collected in larval surveys within either Alviso or the Bair Island Marsh Complexes (Buckmaster, unpublished data). The absence of young juvenile and larval bay shrimp coupled with the abrupt arrival of recruits make it unlikely California bay shrimp successfully reproduced in the sampled marshes during the 2011/2102 winter. Black-tailed bay shrimp were present in both the Alviso and Bair Island marsh trawls beginning in March 2012. As with the California bay shrimp, the CPUE of black-tailed shrimp was higher within the Alviso Marsh. In addition, two specimens of the black-spotted bay shrimp (*Crangon nigromaculata*) were captured at Bair Island. California Department of Fish and Game surveys in South Bay have found black-spotted bay shrimp primarily in cool, high salinity waters, and much of our sampling habitat is simply outside of this species' apparent habitat (Baxter et al. 1998). The obvious difference in the bay shrimp CPUE between Alviso Marsh and Bair Island seems to reflect the higher productivity associated with the Alviso Marsh (the high production within the Alviso Marsh will be discussed later).

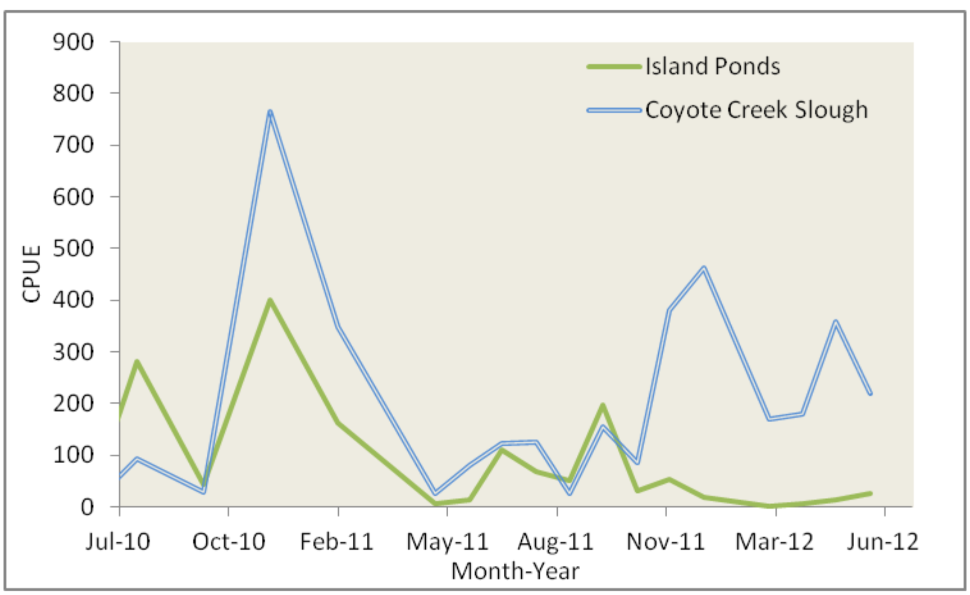


Figure 15. California bay shrimp CPUE for the Island Ponds and the adjacent Coyote Creek (Alviso Marsh Complex)

Trends in bay shrimp abundances remained comparable in restored habitats and slough habitats during the study, with the exception of the Island Ponds in the winter and spring (January to May) of 2012. Despite the apparent abundance of bay shrimp adjacent to the ponds, relatively few were captured inside the ponds. Though measured abiotic parameters taken while trawling the ponds do not explain the absence of shrimp from these habitats, water quality readings taken early-morning showed daily dissolved oxygen swings in excess of 7 mg/l (2.5 mg/l to 9.5 mg/l) during the period during which shrimp were absent from the ponded habitat. Schroeter and Moyle (2004) noted that bay shrimp will avoid water with low dissolved oxygen levels (<2.5 mg/l. Although the diel variations within the Island Ponds keep the pond habitat accessible to sensitive species capable of moving in and out of the habitat rapidly (e.g., surfperch, striped bass), bay shrimp may not be able to move into the pond and escape before the oxygen levels drop.

Other Invertebrate Species

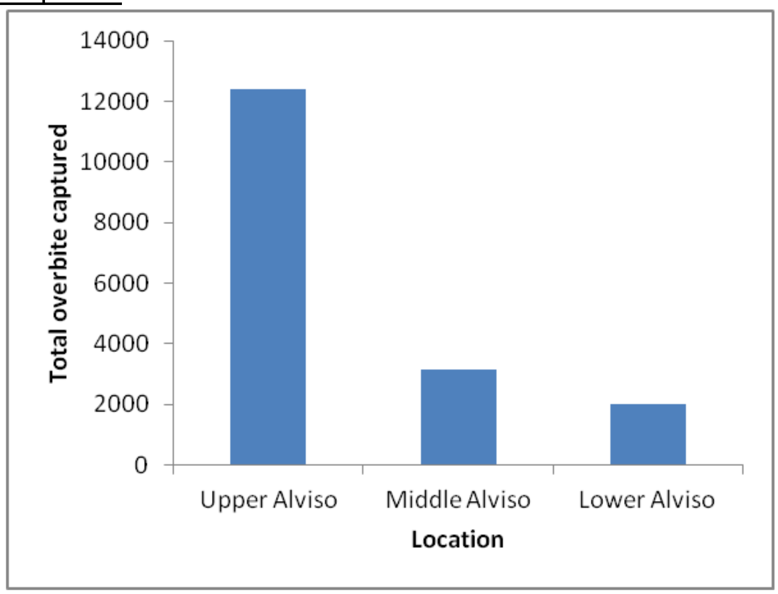


Figure 16. The total overbite clam catch in otter trawls within Alviso Slough.

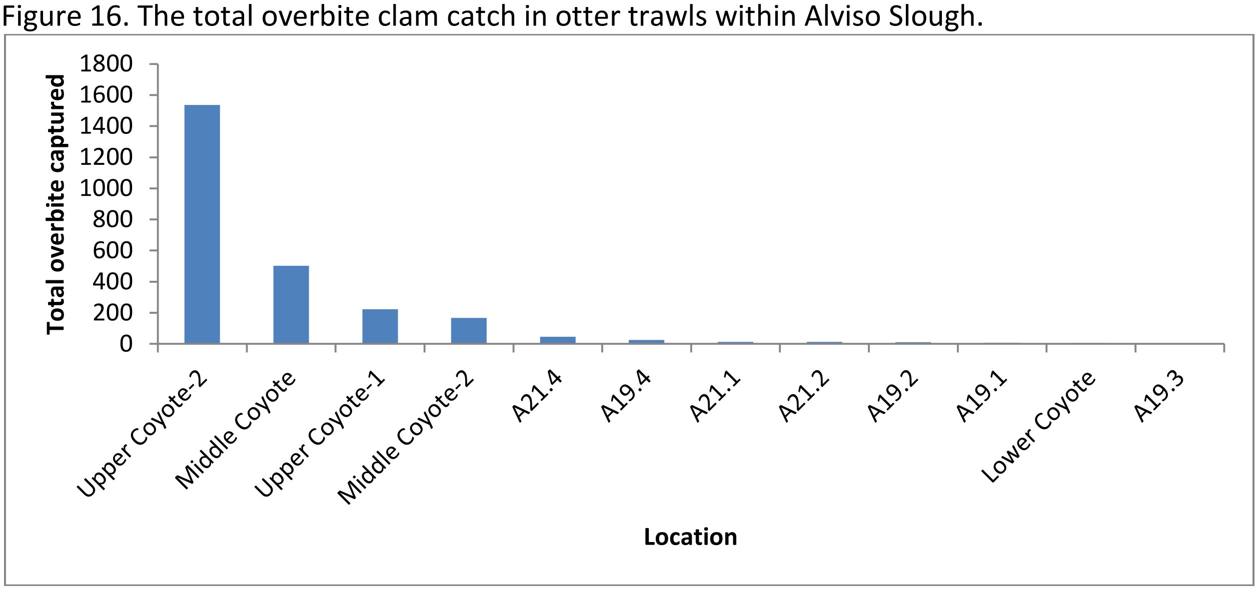


Figure 17. The total overbite clam catch in otter trawls within Coyote Creek and the Island Ponds.

Overbite clam historically were the most abundant bivalve in all of South Bay and have been implicated as causing tremendous declines in macrozooplankton (i.e., mysid shrimp) in San Pablo Bay and the Sacramento/San Joaquin Delta (Kimmer and Orsi 1996, Takakawa et al. 2002). Despite recent declines throughout South Bay (Cloern et al. 2007), our sampling shows overbite clams abundant within the Ravenswood Pond as well as in the Alviso Marsh. Otter trawl CPUE of overbite clam is high within Alviso Slough, especially at the upstream stations adjacent to, but not within, fresh water. Overbite are virtually absent from the lower reaches of Coyote Creek, the Island Ponds, and A6, but they are present in the upper reaches of the tidal portion of Coyote Creek.

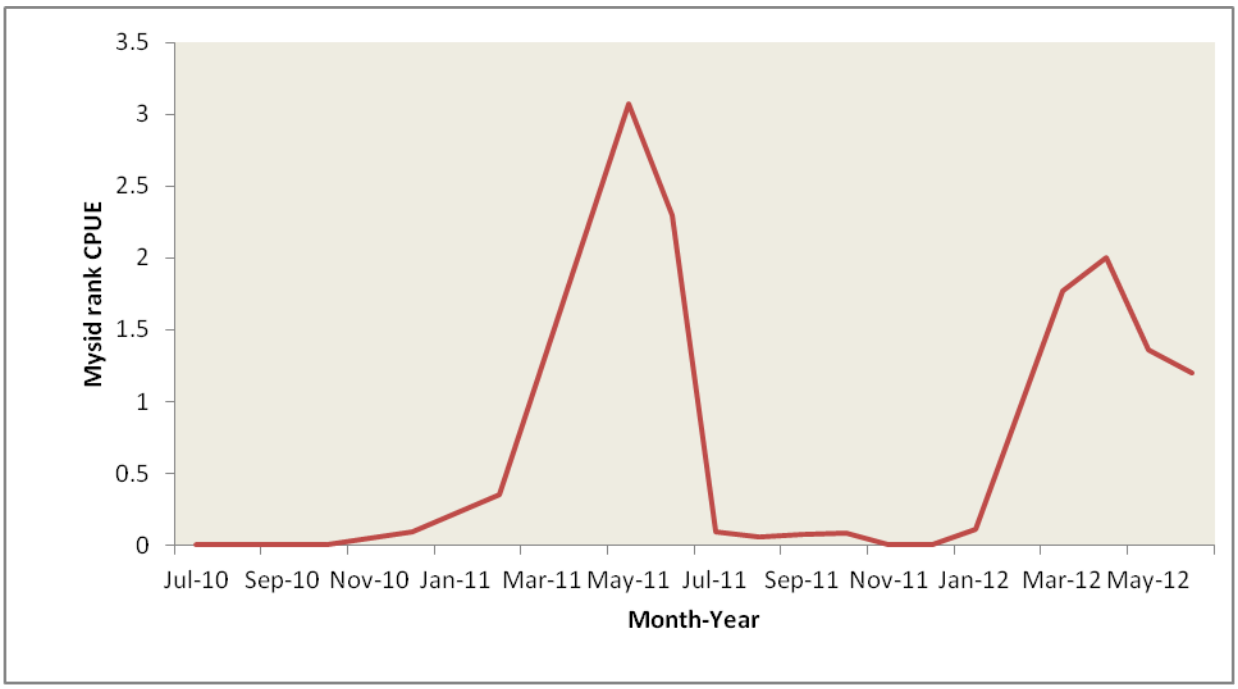


Figure 18. Mysid rank (see methods) CPUE for the Alviso Marsh.

Mysid shrimp were only abundant within the Alviso Marsh and displayed a strong seasonal pattern, reaching maximum abundance in May 2011 and April 2012. Additionally, a bloom of *Alienacanthomysis macropsis*, which is apparently too small to easily capture via otter trawl, was identified in December 2010 and January 2012 (Buckmaster, unpublished data). The dominant mysid shrimp in the spring bloom was the euryhaline species *Neomysis kadiakensis*. Mysid shrimp appeared to be more abundant in the Island Ponds than in the adjacent slough habitats (Figure 19). The bloom appeared to last longer and peak somewhat later in these habitats.

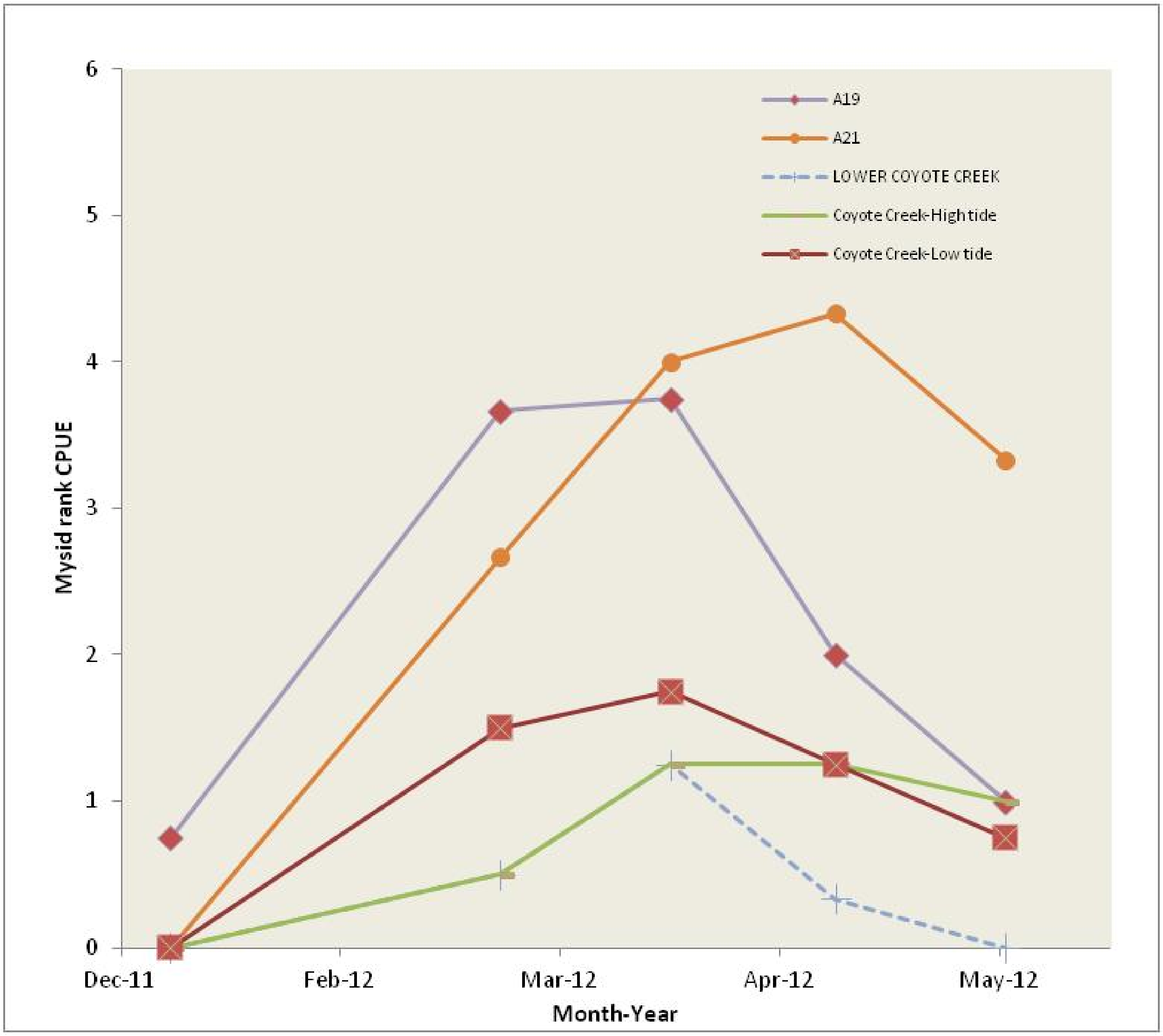


Figure 19. Mysid rank CPUE for Coyote Creek at high and low tide, lower Coyote Creek (adjacent Alviso Slough) and two of the Island Ponds.

In addition to mysid shrimp, amphipods of the family Corophiidae were more abundant within the Island Ponds than in the adjacent slough habitat, presumably due to an increase in organic material in the sediment. Corophiid amphipods tend to be detritivores and are known to filter feed. These amphipods probably forage in the accreted organic material within the restored salt ponds. Corophiid amphipods appear to be tolerant of extremely low DO levels, an adaptation that suites a benthic grazer.

Fish Community Sampling Results

Summary and Marsh Complex comparisons

Because the first year of sampling was largely experimental, most of the discussions will focus on the second year (June 2011 to June 2012). These are abbreviated descriptions of the sampled fish faunas at the study marshes, with some broad comparisons drawn between them. Eden Landing will not be discussed here, and the species captured at Eden can be found in the appendix. Approximately 30,000 fish from 41 species have been captured in the fish community study.

Alviso Marsh Complex

The Alviso Marsh Complex has yielded more species than any other complex and has a higher average otter trawl CPUE than Bair Island or Eden's Landing. Otter trawl CPUE was highest in March 2012, when juvenile fish were rearing within the marsh, followed by September 2011, when the dominant species in the marsh were threespine stickleback and staghorn sculpin (Figure 20, 21). Because of the habitat diversity within the marsh, especially the presence of freshwater inflow, we have found several euryhaline freshwater-dependent fish species within the Alviso Marsh Complex that we have not seen elsewhere [i.e., prickly sculpin(*Cottus asper*) Sacramento sucker (*Catostomus occidentalis*)]. Migratory and resident juvenile fish CPUE within the Alviso Marsh Complex were considerably higher than any of the other sampled habitats, including the shoals and channel of the central South Bay, indicating that Alviso might be important as a nursery for some species [English sole (*Parophrys vetulus*) staghorn sculpin (*Leptocottus armatus)* Pacific herring (*Clupea pallasii*) and others]. In addition, CPUE for threespine stickleback within the Alviso Marsh Complex was higher than any other marsh by three orders of magnitude. A distinct pelagic-fishes assemblage was also abundant in winter months and was only found in the Alviso Marsh Complex. This assemblage included the state-threatened longfin smelt (*Spirinchus thaleichthys*), American shad (*Alosa sapidissima*), and threadfin shad (*Dorosoma petenense*) (Figure 20). Finally, all (71 individuals) striped bass (*Morone saxatilis*) captured via otter trawl were captured within the Alviso Marsh Complex.

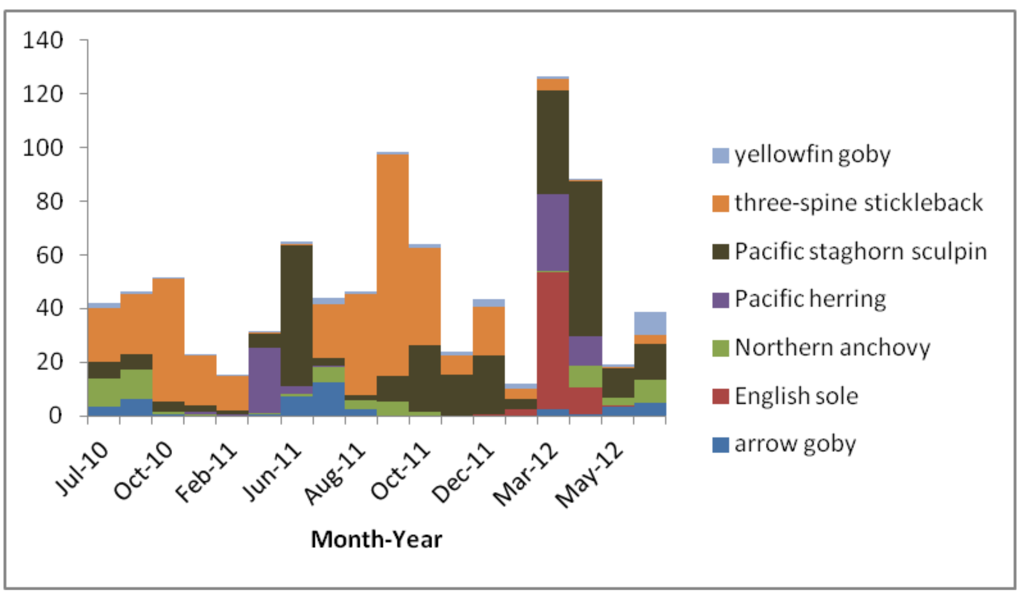


Figure 20a. CPUE of most abundant fishes within the Alviso Marsh Complex for the entire study period.

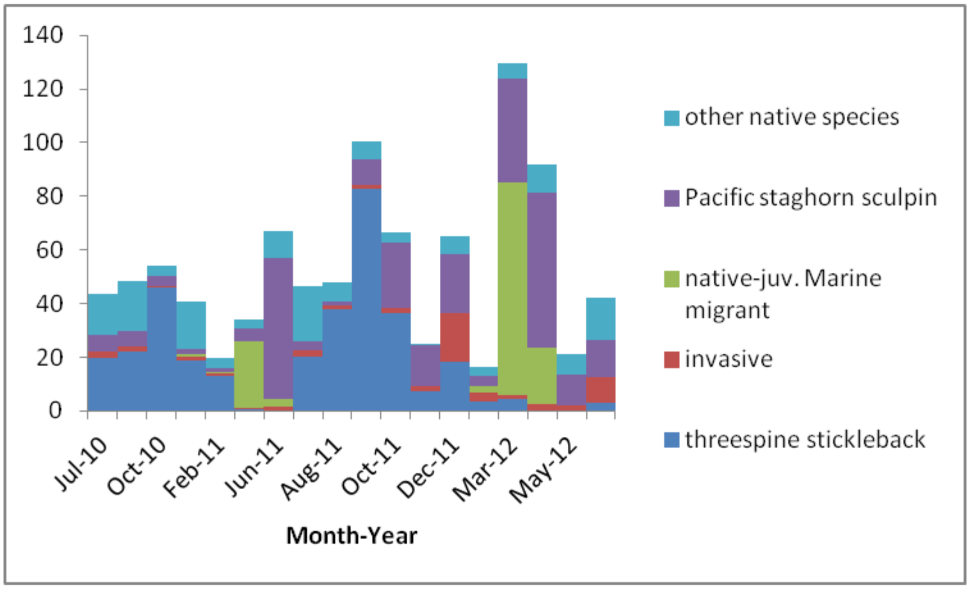


Figure 20b. Total CPUE of all fish in the Alviso Marsh Complex for the entire study. Fish are separated by general classifications: invasive/non-native species, threespine stickleback, Pacific staghorn sculpin juvenile native marine species, and other native species.

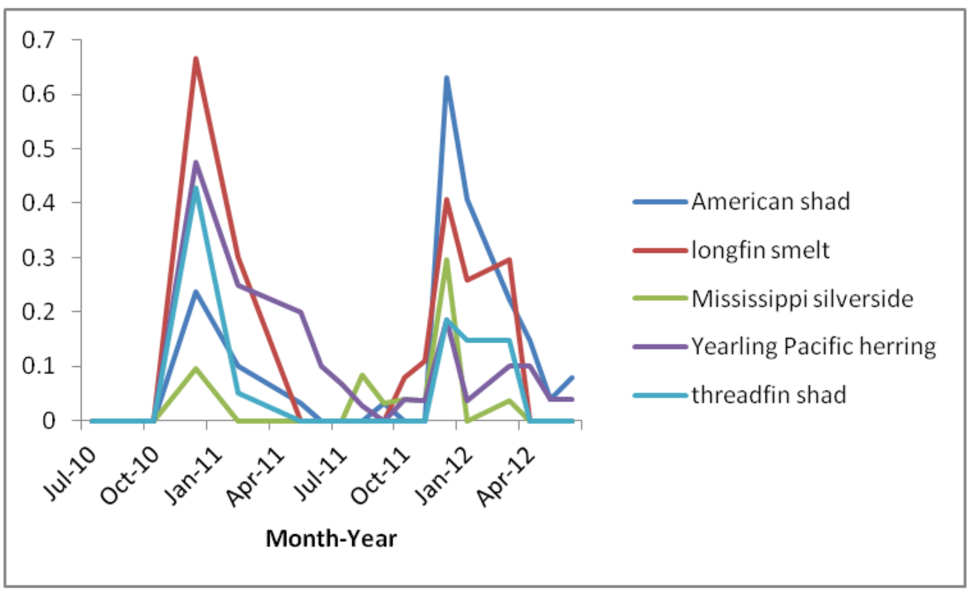


Figure 21. Frequency of occurrence for pelagic fishes in the Alviso Marsh Complex.

Bair Island

On average, the Bair Island Marsh Complex has yielded fewer species than the Alviso Marsh Complex and has a lower CPUE; however, the newly restored Outer Bair Island pond had a CPUE that was comparable to the Alviso Marsh Complex and was considerably higher than elsewhere within the Island. Bair Island CPUE showed a strong seasonal pattern, with lows in both diversity and CPUE occurring in the winter months (December 2010 and November 2011) (Figure 22, 23). Marine and polyhaline fish species had a higher CPUE at Bair Island than at Alviso, but only four species were not found at Alviso [white croaker (*Genyonemus lineatus*), chameleon goby (*Tridentiger trigonocephalus*), brown smoothound (*Mustelus henlei*), and dwarf perch (*Micrometrus minimus*)]. Unlike the Alviso Marsh Complex, Bair Island lacks the dramatic pulse of juvenile fish in the spring months (Figure 23), though species found at Alviso Island are typically present in lower abundance around Bair Island. The juvenile fish most abundant at Bair Island are Pacific herring and staghorn sculpin, followed by English sole and shiner surfperch (*Cymatogaster aggregata*).

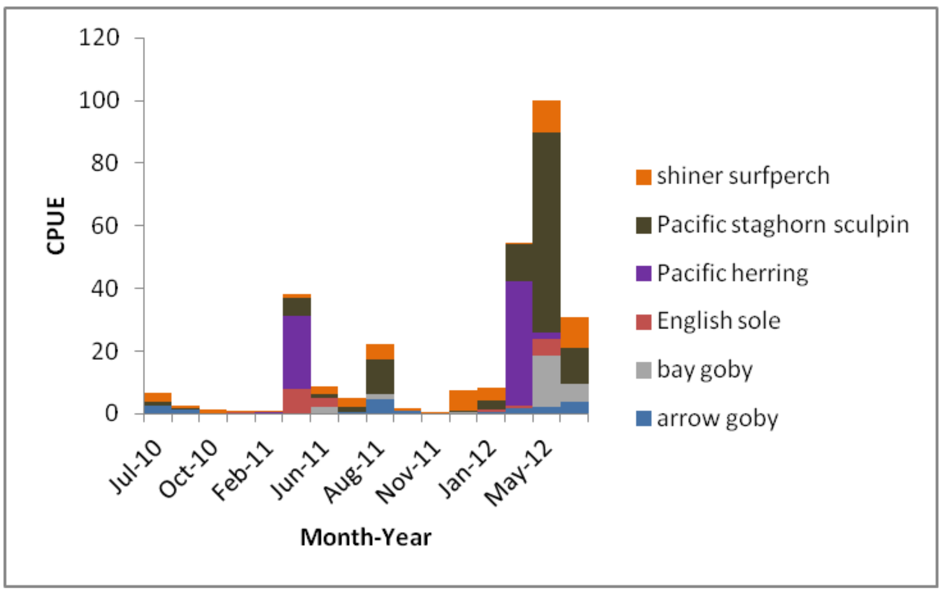


Figure 22. CPUE of the most abundant fish species within the Bair Island Marsh Complex

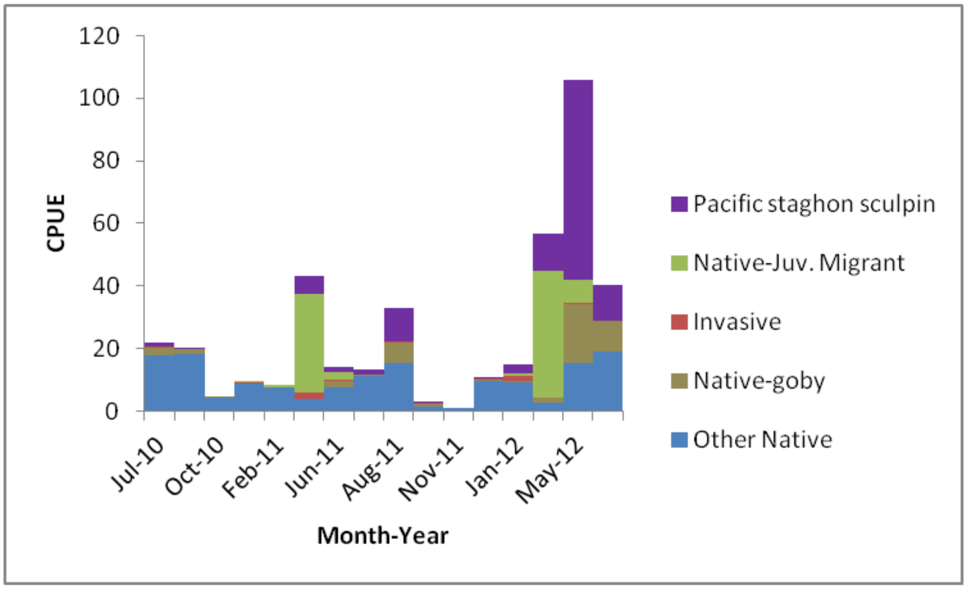


Figure 23. CPUE of all species within the Bair Island Marsh Complex for the last year of the study. Fish are separated by general classifications: Pacific staghorn sculpin, native-juvenile marine migrant, invasive/non-native, native gobiid, and other native fish species. The high catch of Pacific staghorn sculpin in March and May 2012 is due to the initiation of sampling within middle Bair Island.

Ravenswood

CPUE at Ravenswood was highest in the summer season, though the peak seine catch (September 2011) was three months after the peak set-net catch (June 2011), and diversity was highest in February 2011. Because Ravenswood was only sampled with set nets and seines, direct comparisons of CPUE to the Alviso and Bair Island otter trawl surveys are limited; regardless, the use of set nets and seines at the Alviso Marsh Complex and Bair Island makes it possible to compare the communities there to those at Ravenswood. The species assemblage at Ravenswood differs substantially from both Alviso and Bair Island, both in species composition and relative abundances. The dominant species at Ravenswood are atherinopsids [jacksmelt (*Atherinopsis californiensis*) and topsmelt (*Atherinopsis affinis*)] and gobiids [longjaw mudsucker, yellowfin goby, arrow goby (*Clevelandia ios*)]. Pacific herring juveniles were captured in the pond in both February and May 2011; however, they were not abundant during the period and were apparently absent from May 2011 to December 2011. The diversity of the fish community within the Ravenswood pond was extremely low, despite reaching phenomenal abundances in summer months. The warm temperature (26 C<) and low dissolved oxygen levels at night (<1 mg/L) (RWQCB 2011) exceed the lethal limits of fish species common in the adjacent bay. It is clear that poor water quality within the pond precludes most species from entering and remaining in this habitat throughout much of summer and fall. The species observed in Ravenswood during summer months closely resembles the species observed in low-salinity salt ponds still owned and operated by Cargill (Lonzarich and Smith 1997).

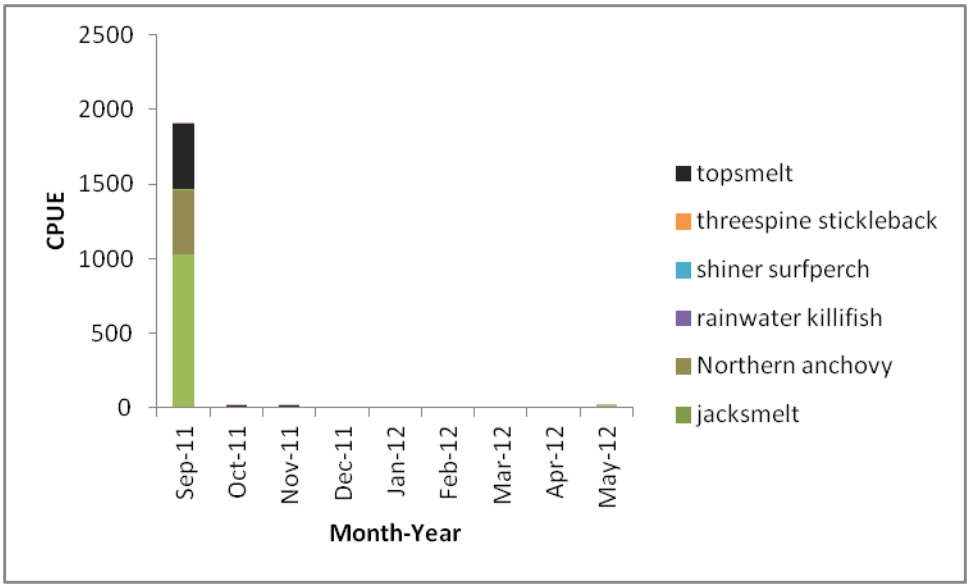


Figure 24. Catch-per-seine-haul at Ravenswood. All species captured are shown.

<u>Species of Concern:</u>

Our surveys have documented the presence of several species of conservation and commercial importance within the sampled marshes: longfin smelt, Chinook salmon California halibut, and white sturgeon.

Longfin smelt

Longfin smelt are an anadramous true smelt (Osmeridae) and are listed as threatened under the California Endangered Species Act. Longfin smelt were present only in the Alviso Marsh Complex and were captured in December 2010 and February 2011 of the first year of sampling and from October 2011 to March 2012. Longfin smelt were the 7th most abundant species in trawls during that period and were captured in all major sloughs and tributary sloughs within the Alviso Marsh Complex. Longfin abundance peaked in December of both years (2010 and 2011), when the catch-per-trawl was over 3.5 individuals. Length-frequency plots indicate two or three modes were present in the Alviso Marsh Complex in December 2011 corresponding to three age classes (0+, 1+ and 2+). The 2011 cohort was the most abundant from October 2011 to December 2011; however, only the larger, reproductively mature cohort remained within the marsh through March 2012.

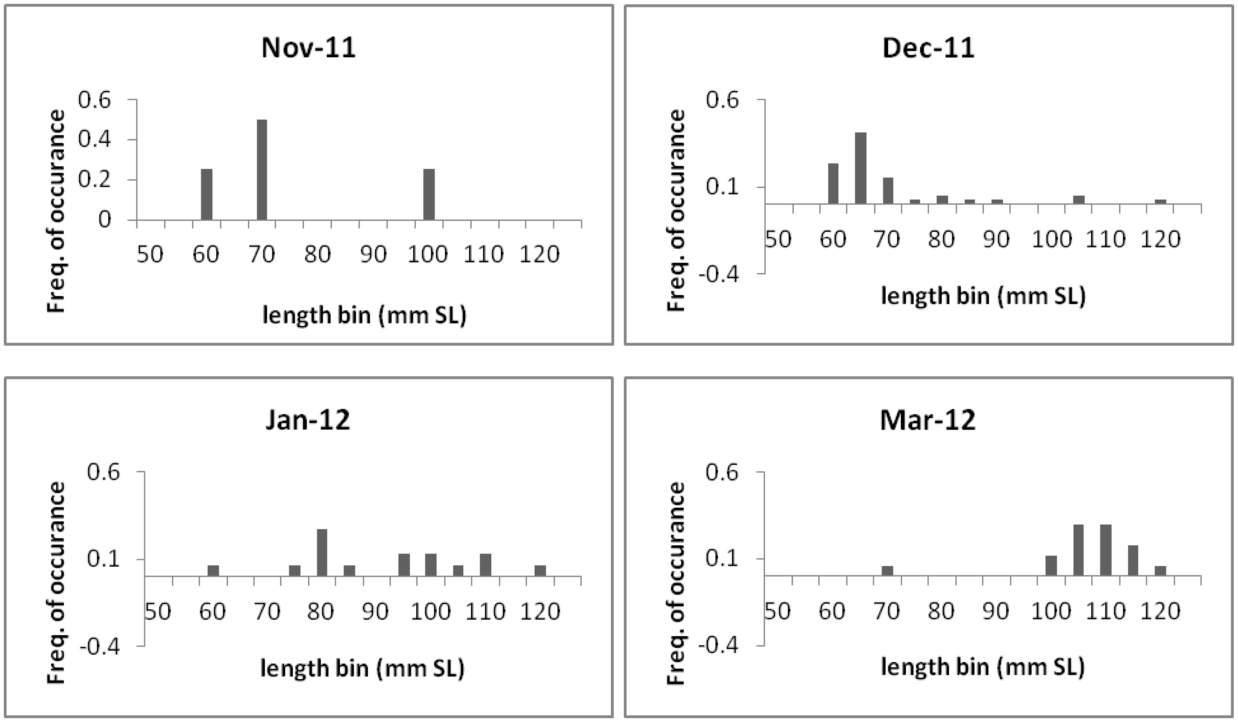


Figure 25. Length frequency distribution of longfin smelt in the Alviso Complex. Bin size is 5mm (e.g., 50-54.99=50).

In late March 2012, Delta outflow increased and caused San Francisco Bay to freshen and likely drew the mature smelt out of South Bay and towards Suisun Bay and the Delta. It is possible that fresh water coming out of local tributaries and the wastewater plant produced enough of a low salinity signature that mature smelt remained around the Alviso Marsh Complex until Delta outflow increased, since they require freshwater to spawn (Emmet 1991). In addition, mysid shrimp (upon which longfin smelt feed almost exclusively) were beginning to increase rapidly in the Alviso Marsh Complex during this period, which undoubtedly increased the attractiveness of this habitat to longfin smelt. Because mysid shrimp have decreased elsewhere in the Bay/Delta, their abundance within the Alviso Marsh Complex presents a compelling explanation for longfin smelt's presence and abundance in this area (especially immature fish). In spite of gravid adult smelt being captured within the Alviso Marsh Complex, larval fish surveys of the Alviso Marsh Complex did not indicate successful spawning occurred in either the winter of 2010/2011 or 2011/2012.

Photo 3. Longfin smelt captured via otter trawl in Coyote Creek (Alviso Marsh Complex) in December, 2010. Photo: Amy Chandos.

Salmon and Steelhead

Chinook salmon have been known to spawn in both Coyote Creek and the Guadalupe River (Liedy 2007). It is likely that these fish are strays from northern streams, as the persistence of an anadromous salmonid population in the Alviso Marsh Complex would have been unlikely given the chronic, year-round hypoxia (<3mg/L) that persisted in the sloughs from ~1900 to ~1970 (USGS SFB WQ monitoring 2012 and Skinner 1962). A single Chinook smolt that was fall-run size was captured in Coyote Creek adjacent to Pond A19 on March 19, 2012. No other salmonids have been captured or observed during our surveys.

All Chinook salmon that enter Coyote Creek and the Guadalupe River do so at the same time fall-run fish enter the Sacramento/San Joaquin river drainages (Leidy 2007), implying that fish in these systems are all fall run. Garcia-Rossi and Hedgecock (2002) found that Chinook in the Guadalupe drainage were strays from the Central Valley and Oregon stocks, and it is likely that the same is true of Coyote Creek. Chinook were absent from both drainages until the 1980's when flow increases for groundwater recharge allowed adult fish to ascend the streams (Leidy 2007). In the early 2000's, over 200 adult Chinook spawned in the Guadalupe River, though the run has tapered off since (Leidy 2007). Run sizes on Coyote are largely unknown, but the possibility of a run becoming established in that drainage cannot be discounted.

Coyote Creek was one of the last streams to support a population of the now-endangered Coho salmon (*Onchorynchus kisutch*). The Coho run on Coyote Creek lasted until the mid-1950's, when the construction of Coyote dam prevented them from reaching their spawning grounds (Leidy 2007). In addition to Coho, spawning pairs of Chum salmon (*O. keta*) also ascended the Guadalupe River in 2002, 2003, 2004 and 2005, raising the question of whether a small run of chum salmon has become established in the drainage (Leidy 2007).

There is historical evidence that steelhead spawned in both Coyote Creek and the Guadalupe Rivers as late as the 1950's (Leidy 2007), and remnant steelhead populations still exist in both Anderson and Coyote reservoirs, as well as in the streams of both drainages.

Because *O. mykiss* is a polymorphic species, with a stream-resident life history (i.e. rainbow trout) and a migratory life history (if anadromous it is called a steelhead), resident "rainbow trout" can give rise to anadromous "steelhead" at any point. With viable trout populations in both drainages, the possibility of steelhead occurring in either drainage is fairly high (however, few surveys have been conducted). In fact a single steelhead smolt was captured by East Bay Regional Parks in the spring of 2012 in lower Alameda Creek (which drains into Eden Landing), which is a system virtually identical to Coyote Creek. Two adult steelhead also returned to Alameda Creek in the winter of 2008, and successfully spawned after being transported around the BART weir.

Photo 4. Chinook salmon from Coyote Creek.

California halibut

California halibut are one of the most popular game fish in San Francisco Bay, in-spite of only limited spawning within the bay and no spawning occurring on the coastal shelf (Baxter et al. 1999). None were captured in our field areas until March 2012, when juveniles were captured at both Alviso and Bair Island. Halibut have remained in both marshes and have been found as far upstream as Warm Springs Marsh in Coyote Creek. California halibut have been captured inside Pond A21 (Alviso Marsh Complex) but not inside any other restored ponds.

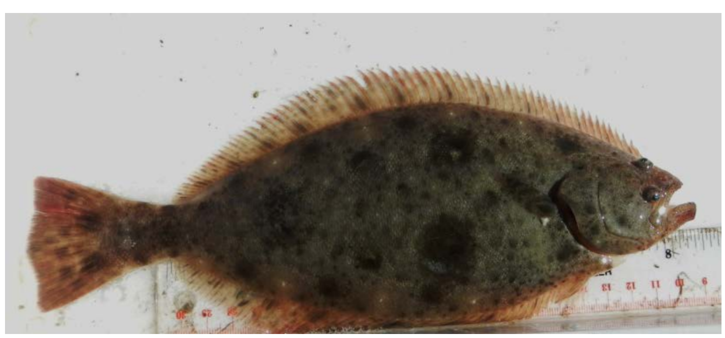


Photo 5. Juvenile California halibut from Bair Island.

White sturgeon

White sturgeon is another popular game fish in San Francisco Bay and is heavily targeted by anglers in the Alviso Marsh Complex. Though not captured in large numbers, our preliminary surveys indicate that adult sturgeon are considerably more abundant in the Alviso Marsh Complex than at any other restoration marshes in South Bay. Though a single white surgeon has entered the Guadalupe River in recent times, the paucity of spawning gravel and of large, sustained flows in both Coyote Creek and the Guadalupe River make it extremely unlikely that sturgeon reproduce in this area (D. Salsbery, personal communication). Instead, it appears that the high sturgeon population in the Alviso area is due this area's historic inaccessibility (and therefore shelter from fishing pressure) and high densities of overbite clam and *Crangon* shrimp, both favorite prey of sturgeon.

Photo 6. White sturgeon captured in Coyote Creek. The animal had a prominent wound on its back, probably from a collision with a prop.

Fish species of interest:

Here we will highlight the seasonal abundance patterns of fish commonly found in and around restored habitats. This provides a background with which to view the subsequent comparative analysis of the communities found within the restored ponds. As with the invertebrate section, only the second year of sampling when effort was standardized will be discussed here unless otherwise noted.

Threespine stickleback

Threespine stickleback (*Gasterosteus aculeatus*) was the most numerous fish captured in the otter trawl surveys and constituted 31% of the total catch (8435 individual stickleback). Threespine stickleback (referred to as stickleback hereon) are one of the most abundant bait fish in the Alviso area. Several species of fish (e.g., striped bass) and birds (egrets, herons, terns) have been observed feeding on them during the summer and fall months. The vast majority of stickleback were captured within the Alviso Marsh Complex; only a single individual was captured at Bair Island, and less than 20 were captured at Eden Landing. Within the Alviso Marsh Complex, stickleback were most abundant within the Island Ponds and in upper Coyote Creek, directly adjacent to Warm Springs lagoon. The Alviso stickleback population appears to be annual, and the CPUE is highest in late summer (Figure 26a), following a period of spawning and recruitment that begins in May (Figure 26b).

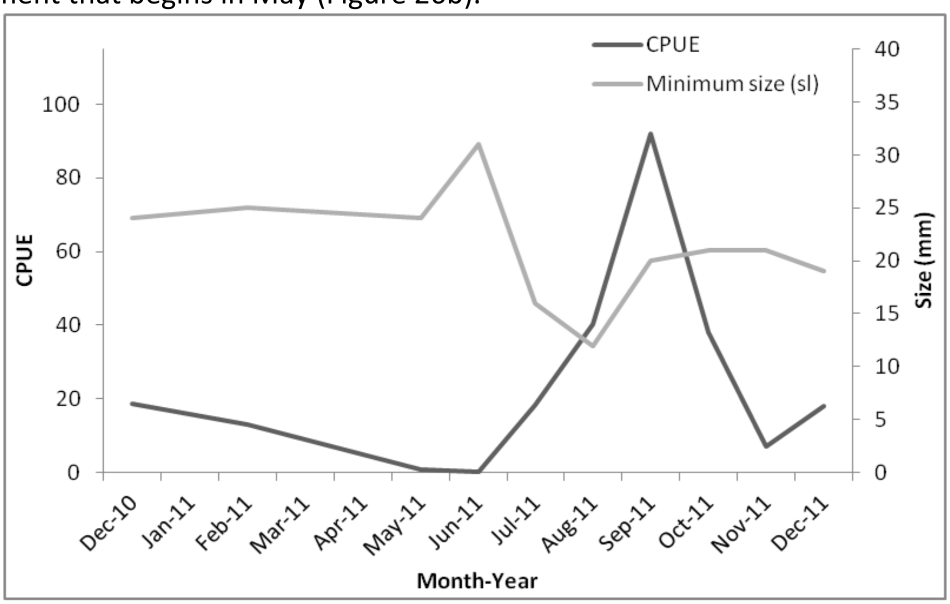


Figure 26. Annual pattern of CPUE for threespine stickleback in the Alviso Marsh Complex and the minimum size of stickleback captured via otter trawl in the Alviso Marsh Complex. Smaller fish indicate ongoing recruitment to the trawl (i.e. July and August, 2011 and April to June 2012), while the absence of small stickleback indicate there is no recruitment.

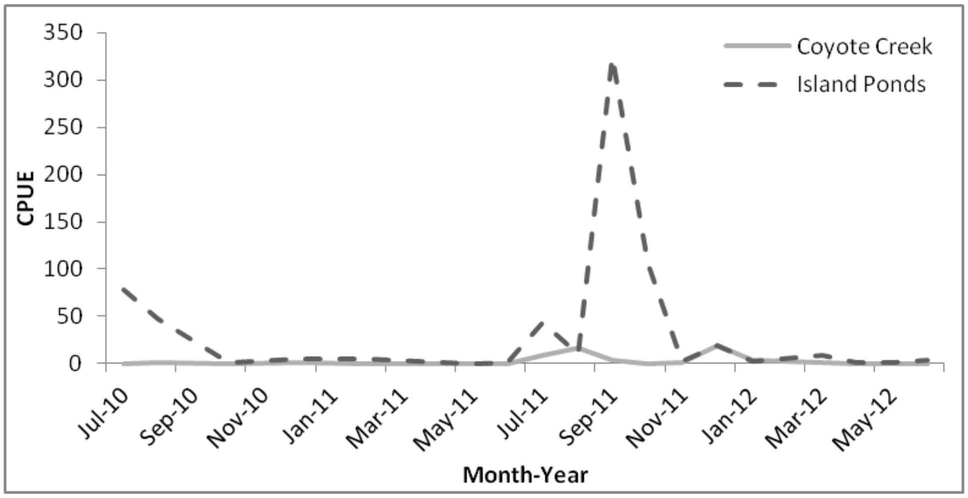


Figure 27. CPUE of threespine stickle back in the Island Ponds and Coyote Creek.

As an annual, physiologically tolerant species, threespine stickleback are one of the fish species most likely to benefit from the initial stages of tidal marsh restoration. Because threespine stickleback are an important prey item both within the Alviso Marsh Complex and in Suisun Marsh (O'Rear and Moyle 2011). Ultimately, increased populations of threespine stickleback benefit piscivorous fish and birds.

Pacific staghorn sculpin

Photo 7. Pacific staghorn sculpin adult captured via otter trawl in Alviso Slough.

Pacific staghorn sculpin (staghorn) are the second most abundant species in our otter trawl surveys and make up a significant portion of the minnow trap catch as well. Staghorn are one of the few fish species to increase in abundance in San Francisco Bay since 1973 (Moyle 2002 and Baxter et al. 1999). Because staghorn are abundant throughout the year at Alviso but only seasonally at Bair Island, the two marshes will be discussed separately.

Bair Island Marsh Complex:

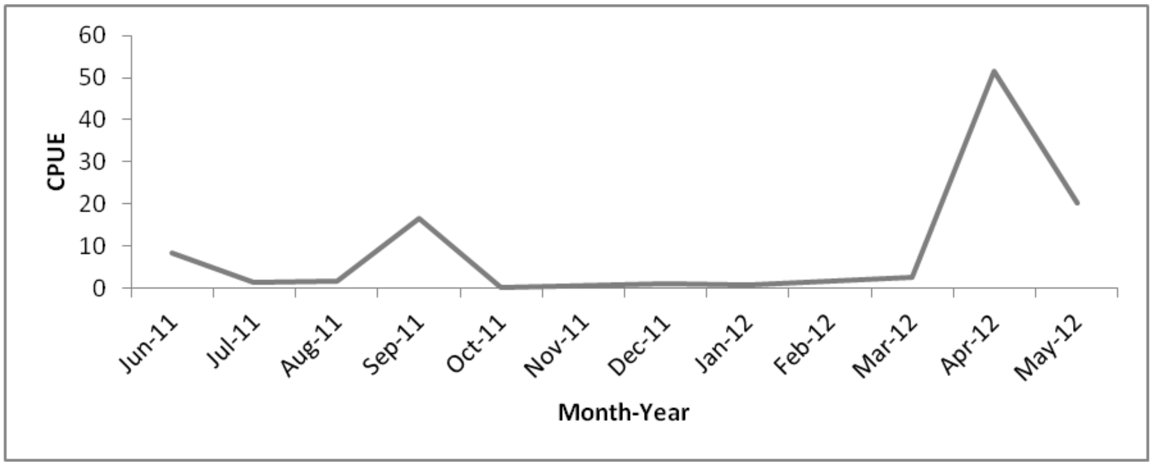


Figure 28. Pacific staghorn sculpin CPUE at Bair Island for the duration of the study.

Staghorn catch within Bair Island and the adjacent sloughs (excluding Outer Bair Island) was relatively low, and peak in CPUE occurred in April 2012 (following settlement of the 2012 cohort). The diked saltmarsh east of Outer Bair Island is the oldest restored habitat in the area and did not support many staghorn despite the appearance of quality habitat. In addition, staghorn captured in this pond showed several deformities, including scoliosis and the formation a second jaw. Presumably, dredge tailings from the Port of Redwood City contaminated the central pond and thus limited its effective value for staghorn.

Outer Bair Island, however, was heavily used by staghorn sculpin young-of-year during the winter and spring of 2011/2012. CPUE of staghorn in this habitat was one to two orders of magnitude higher than in the adjacent Steinberger Slough, indicating that staghorn sculpin were not only using this habitat but almost certainly breeding in it as well. CPUE patterns in the newly restored habitats indicate that following recruitment and a brief rearing period, staghorn sculpin emigrated from the pond.

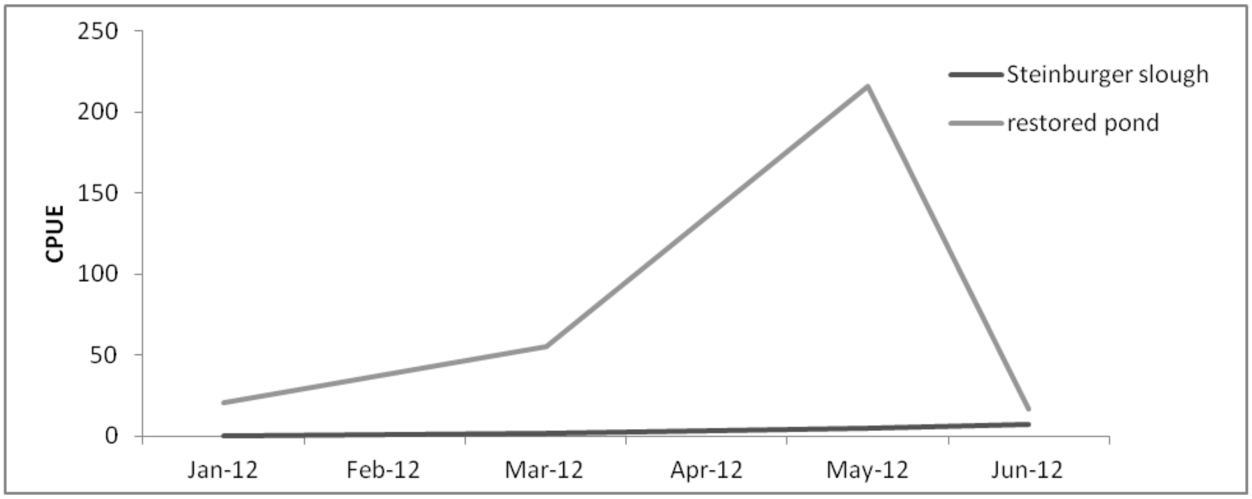


Figure 29. CPUE of Pacific staghorn sculpin in Steinberger Slough and the newly restored pond, Outer Bair Island.

Alviso Marsh Complex:

Staghorn sculpin were phenomenally abundant in the Alviso Marsh Complex throughout the year and have been harvested by the bait industry based out of the Port Alviso (CDFG 2012). The CPUE of staghorn sculpin in the second full year of sampling peaked in March, following the settlement of the 2012 year class (Figure 30). Staghorn sculpin had a protracted spawning period within the Alviso Marsh Complex, and newly transformed sculpin were abundant in otter trawls from December to April and peak recruitment occurred from January to March (Figure 31). Like the newly breached pond at Bair Island, large numbers of young staghorn were observed in Knapp's Tract (Pond A6).

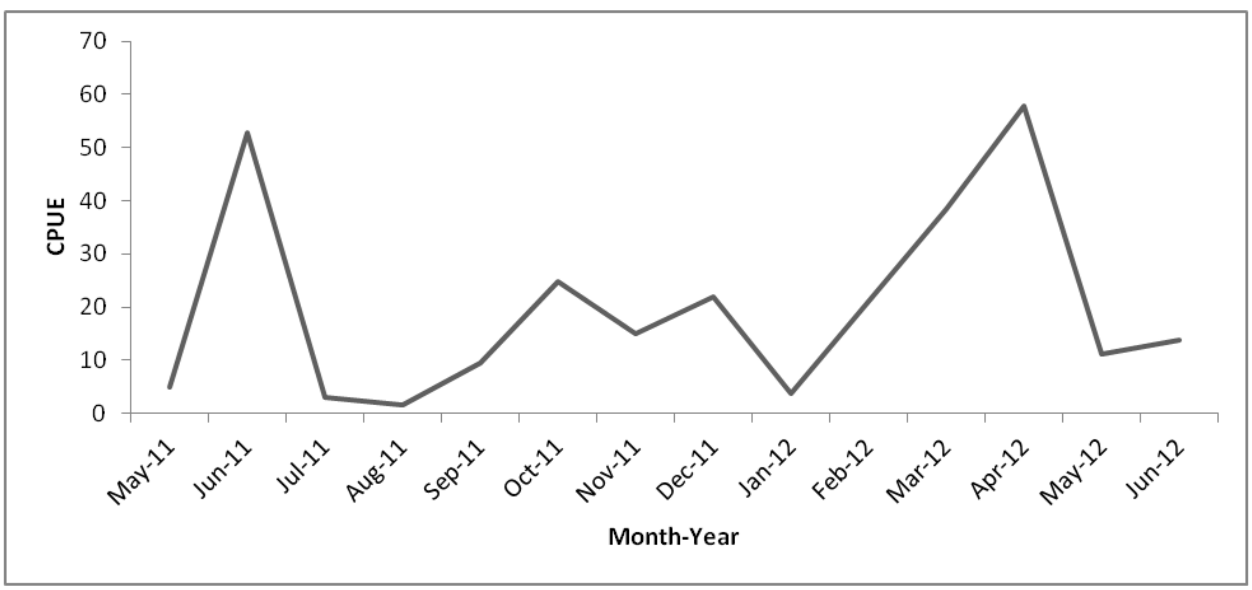


Figure 30. CPUE of Pacific staghorn sculpin (all size classes) within the Alviso Marsh

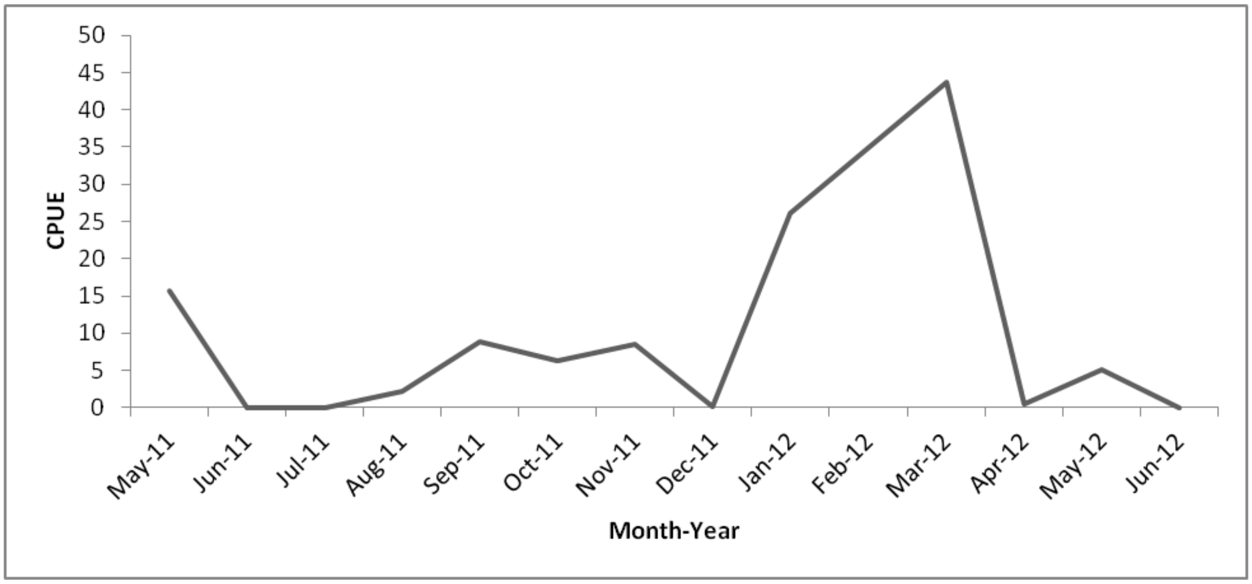


Figure 31. CPUE of newly transformed (<25mm SL) staghorn sculpin within the Alviso Marsh.

The CPUE of adult staghorn sculpin increased within the Alviso Marsh Complex in September and remained above average through November (Figure 30). Presumably, these staghorn were moving into the area to spawn, and examinations of mortalities revealed fully developed ovaries in females. The presence of newly transformed staghorn in otter trawls during this period corroborates this. However, commercial harvest of staghorn decreased during this period, and the observed increase in CPUE might have been impacted by this (i.e., there was a continual immigration of staghorn into the marsh, but commercial harvest kept abundances constant over this period).

Staghorn sculpin young-of-year actively seek out fresh water (Jones et al. 1962, Moyle 2002), and the distribution of young-of-year staghorn sculpin within Coyote Creek and Alviso sloughs reflected this, with higher abundances at upstream locations during spring and summer. Because of the position of the A8 notch, adjacent to the Guadalupe River, it is likely that this upstream movement makes staghorn likely candidates to invade this habitat when the notch is opened at the beginning of summer of both 2011 and 2012. When the notch in A8 opens the salinity of Alviso Slough increases, and staghorn sculpin CPUE declines. This decline is due to emigration from Alviso Slough into A8, or the reduced attractiveness of Alviso Slough for Staghorn sculpin.

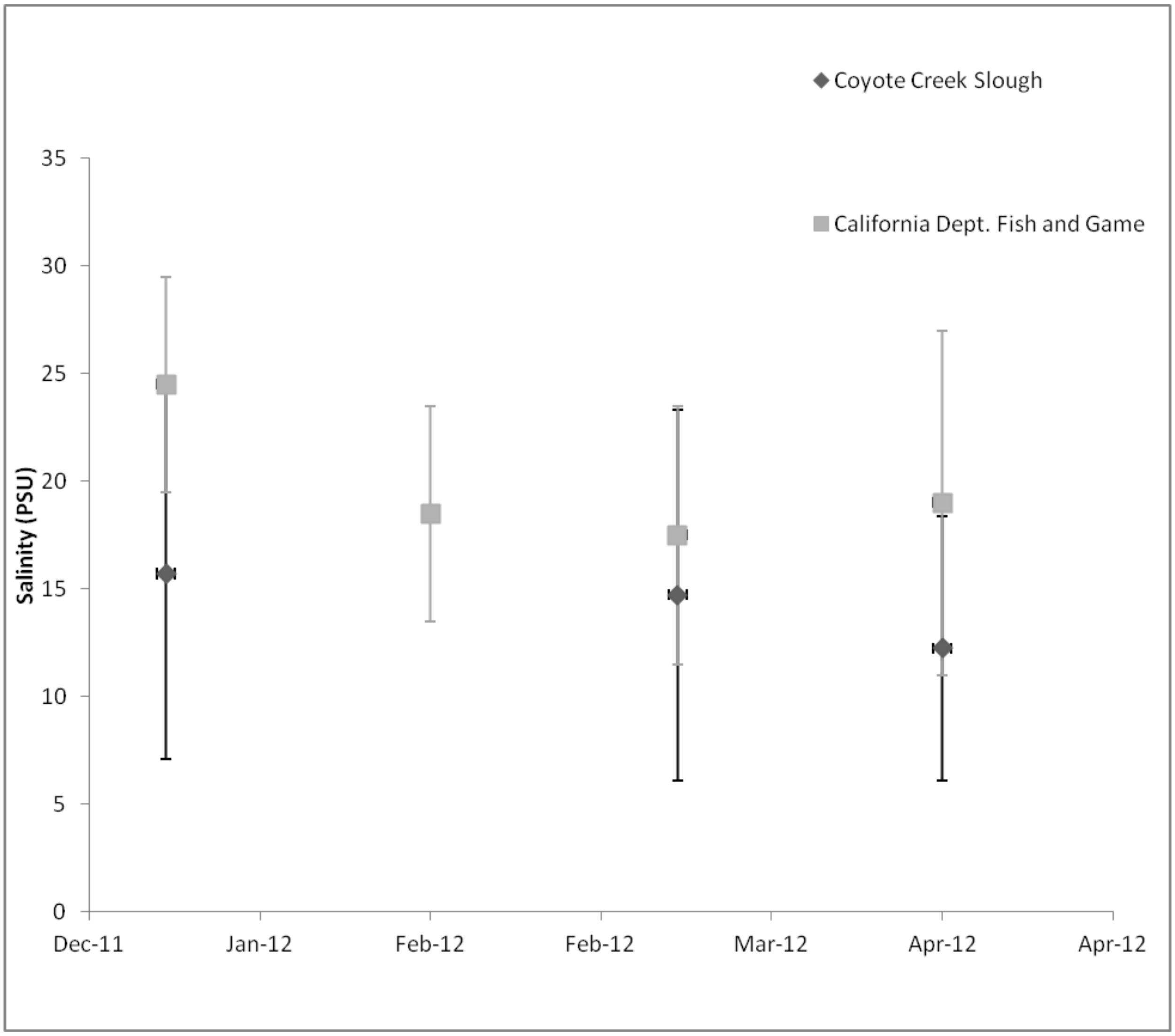
Like threespine stickleback, Pacific staghorn sculpin are a common prey item for predatory fish such as striped bass and leopard sharks and for wading birds such as egrets and herons. High numbers of staghorn in and around the restoration areas ultimately will provide increased foraging opportunities for these species.

English Sole

Photo 8. Young-of-year English sole captured via otter trawl in Alviso Slough. Photo: Matt Young.

Adult English sole are marine oriented; prefer cool, deep channels; and are rarely captured in our surveys. Young-of-year English sole, however, migrate in large numbers into San Francisco Bay and rear in Central, San Pablo, and South Bay (Orsi et al 1998). This facultative estuarine rearing strategy is common among California marine fishes, as there are few truly estuarine-dependent fish species, leaving little completion for small juveniles. English sole are one of the most common of such fish in our surveys, but there are numerous others (e.g., California halibut, speckled sanddab, Pacific herring, leopard shark, and starry flounder). English sole were most abundant within the Alviso Marsh Complex, although in both 2011 and 2012, there was a brief increase in English sole CPUE at Bair Island the month following their decline at the Alviso Marsh Complex. This pattern is consistent with the observation that English sole move into coastal waters after their first year of life, though in low outflow years larger sole will remain in Central San Francisco Bay (Rooper et al. 2002 and Baxter et al. 1999).

What makes English sole relevant to our questions pertaining to salt pond restoration was their location within the Alviso Marsh Complex. English sole are very rarely collected below 18 ppt throughout most of their range (Rooper et al 2002), though CDFG surveys from San Francisco Bay report that sole will frequent waters from 13-24 ppt in spring months. However, within the Alviso Marsh Complex, English sole were most abundant adjacent to the Island Ponds and Knapp's Tract in water that is fresher (as low as 6ppt) than their apparent preferences. In regions of the marsh where salinities are closer the reported optimal, English sole are considerably less abundant.



Fiugre 32. CPUE-weighted average salinity of English sole capture in Coyote Creek and the entire San Francisco Bay (reported by CDFG in Baxter et al. 1999). Error bars are ±1 SD.

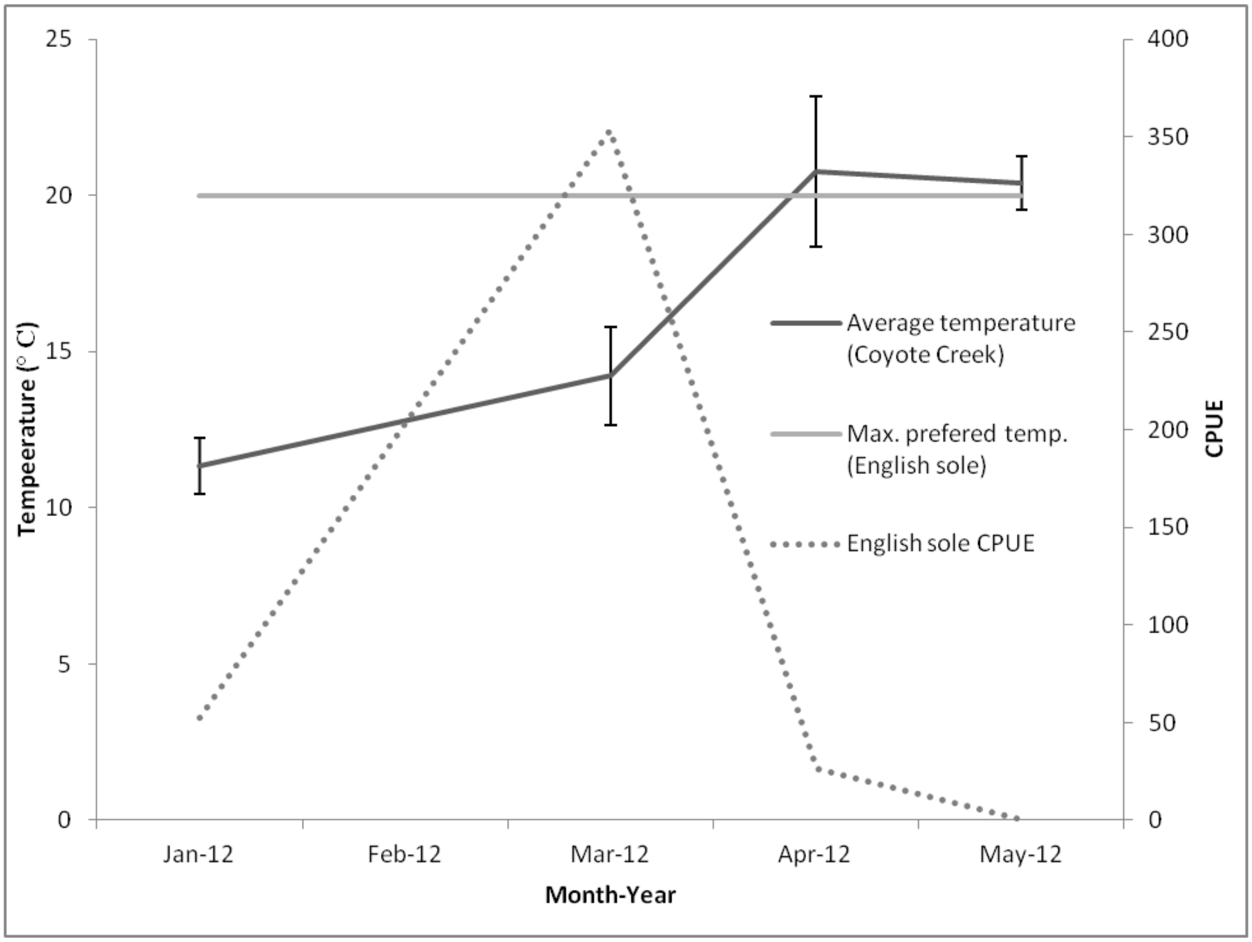


Figure 33. English sole remain in Coyote Creek until the temperature exceeds 20° C, at which point they move into cooler waters.

English sole are a species that frequently uses the marine portions of estuaries as nursery habitats, but within the Alviso Marsh Complex it appears as though English sole are moving into, and remaining in, lower-salinity water adjacent to restoration areas. Other studies have found similar patterns in flatfish across the Pacific, including one definitive study of stone flounder (*Platichthys bicoloratus*), in Japan. Yamashita et al.(2003) showed that stone flounder young-of-year rearing in low salinity habitats had increased stress hormones; however, these fish only remained in these osmotically stressful environments when prey was sufficient to support extremely rapid growth. As a result, the most stressed individuals also grew the fastest and had the best survival index.

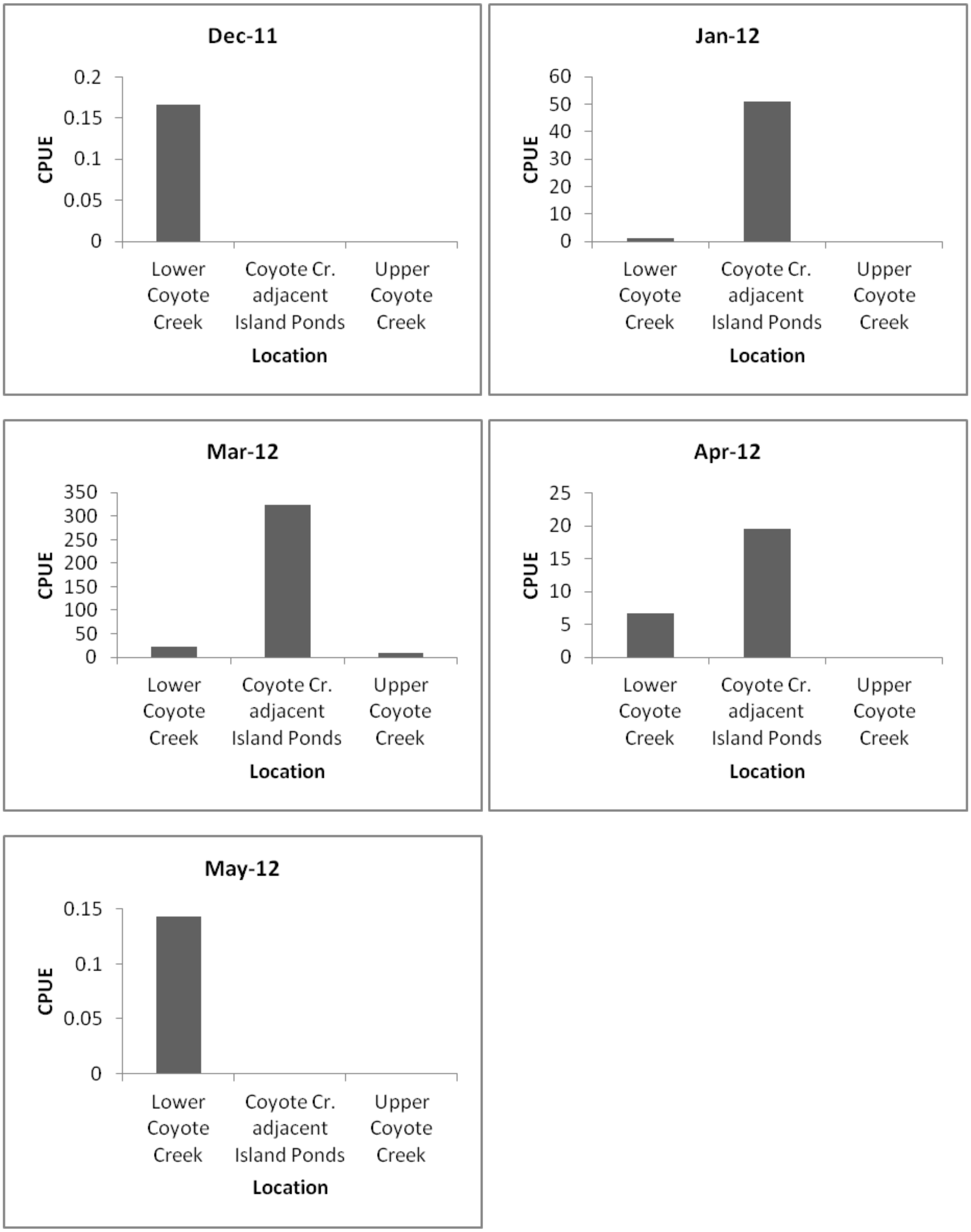


Figure 34. CPUE of English sole within the Alviso Marsh. The axes are scaled to account for drastic differences in CPUE. Because English sole catch within the borrow ditches of the Island Ponds was dependent on tide stage (when the surface of the ponds were inundated, no sole were captured), the ponds are excluded from the above diagram.

Pacific herring

Photo 9. Pacific herring captured via otter trawl in Alviso Slough. Photo: Matt Young.

Pacific herring are another marine immigrant that uses bays and estuaries of the Pacific Coast as rearing habitat. Herring are a commercially important species harvested for meat as well as roe. Unlike English sole, which move into San Francisco Bay as juveniles, Pacific herring adults actually spawn inside of the Golden Gate, and the larvae are present throughout the bay (Alderice and Velsen 1971, Orsi et al 1998). Like English sole, Pacific herring recruits are more abundant within the Alviso Marsh Complex than at Bair Island, Eden Landing, or SF2, though recruits are present at all locations.

Like English sole, Pacific herring generally select waters of higher salinity (21 ppt) in which to rear. Within San Francisco Bay, newly transformed herring were found in salinities ranging from 13-28 ppt (Orsi et al. 1998) and salinities below 10 ppt were extremely stressful to juvenile herring (Holliday and Blaxter 1961, Garrison and Miller 1982). As Pacific herring increased in size, the salinity at which they occurred in also increased (Orsi et al. 1998). However, similar to English sole, Pacific herring CPUE was higher in the low-salinity areas adjacent to the Island Ponds and up Coyote Creek to Warm Springs Marsh. April and May are typically when Pacific herring young-of-year begin to migrate towards the higher salinities and cooler temperatures of Central Bay (Orsi et al. 1998). However, Pacific herring CPUE in the Alviso Marsh Complex was highest within A19 and Warm Spring Marsh, where salinity was nearly fresh (<5 ppt). This would also indicate that Pacific herring juveniles are moving into and utilizing restored marshes, despite these environments being osmotically stressful.

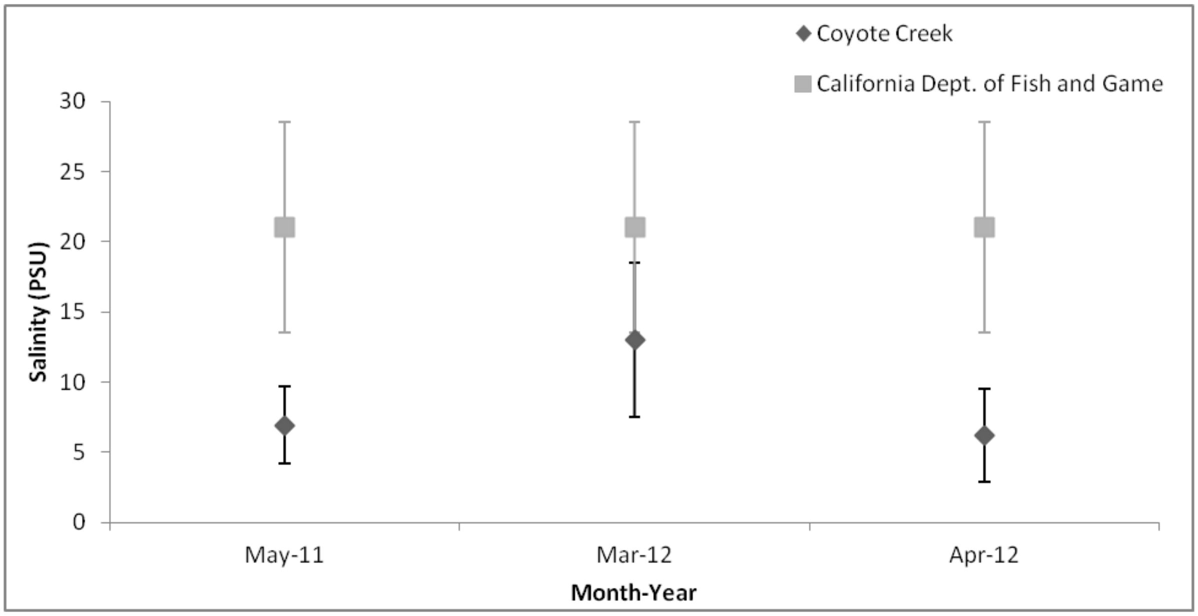


Figure 35. CPUE weighted average salinities where young (~30-40 mm SL) Pacific herring were captured in Coyote Creek and the long-term average salinities where comparably sized Pacific herring were captured in San Francisco Bay (Orsi et al. 1998). Pacific herring are only abundant in Alviso Marsh for ~2-3 months a year. Error bars are ±1 SD

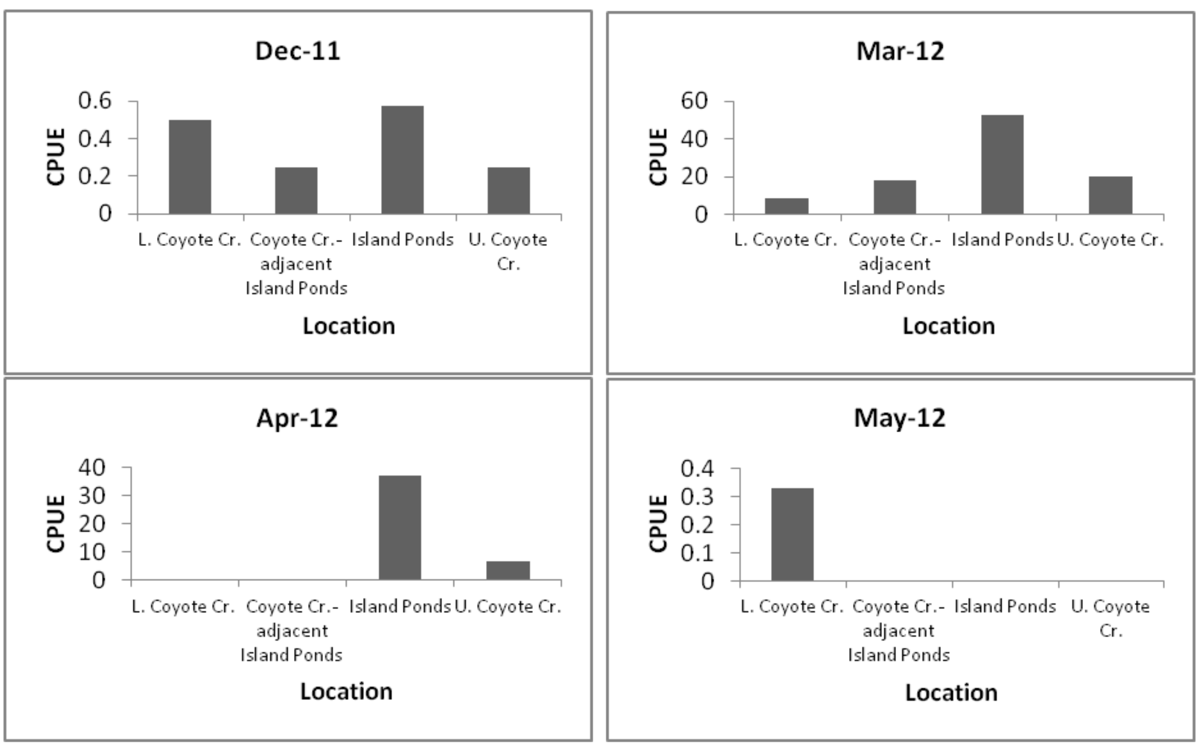


Figure 36. CPUE of Pacific herring in Coyote Creek and the Island ponds. Axes are scaled to account for monthly differences in CPUE. The high CPUE of Pacific herring in Upper Coyote Creek in April occurred in our inaugural sampling of Warm Springs Lagoon.

The high CPUE of juvenile marine immigrants such as Pacific herring and English sole within the Alviso Marsh Complex, and their position within the marsh, indicates that the Alviso Marsh Complex (especially adjacent to restored salt ponds) might actually function as nursery habitat for several species. Whether this is due to salt pond restoration has not been determined; however, seasonal surveys conducted immediately prior to the Island Pond restoration (Takekawa et al. 2005) did not document either species in the area. Historical surveys from 1980-1986 (Stevenson et al. 1987) documented both species in South Bay, but not upstream of Calaveras Point, implying that these fish might have not been using this area as extensively during this time. However, less frequent sampling, different methods, and bay-wide changes in fish communities make this conclusion tenuous. Further investigation into possible mechanisms underlying the relationship between breached ponds and fish communities is needed.

Salt Pond Restoration: Community level

Using similarity indices provides a quantitative method that allows us to determine if restored salt ponds support similar fish species assemblages, both between salt ponds and between restored ponds and sloughs. Such indices also give the extent to which communities differ. Should salt ponds support different assemblages, the species colonizing the habitat will reflect the conditions created by the salt pond and be indicative of the fish communities' response to restoration. Alternatively, should the assemblages be identical between the ponds and sloughs, it is likely salt pond restoration has very few effects on slough fish and provides habitat that is identical to the sloughs. Future, more complex analysis will seek to further address this question, depending on the ability of the data to meet the requisite assumptions. Because of sampling consistency, the Island Ponds in the Alviso Marsh will be used as an example.

The Islands Pond fish assemblage is most similar to the adjacent Coyote Creek in winter and spring, and least similar in summer and fall, as seen in both 2010/2011 and 2011/2012. Most fish found in Coyote Creek were also found in the adjacent Islands Ponds, which is reflected in a consistently high Sørensen similarity index between the two habitats; however, fewer species are shared during the summer and fall months (Figure 37a). The relative abundances of the fish species that comprise the two communities are rarely similar in both the restored ponds and the slough, and in the summer to fall period the dominant community members are extremely different, as indicated by a low Bray-Curtis similarity index during this period (Figure 37b). Because the spring of 2011 was cooler and wetter than the spring of 2012, this "summer" pattern began later in the season.

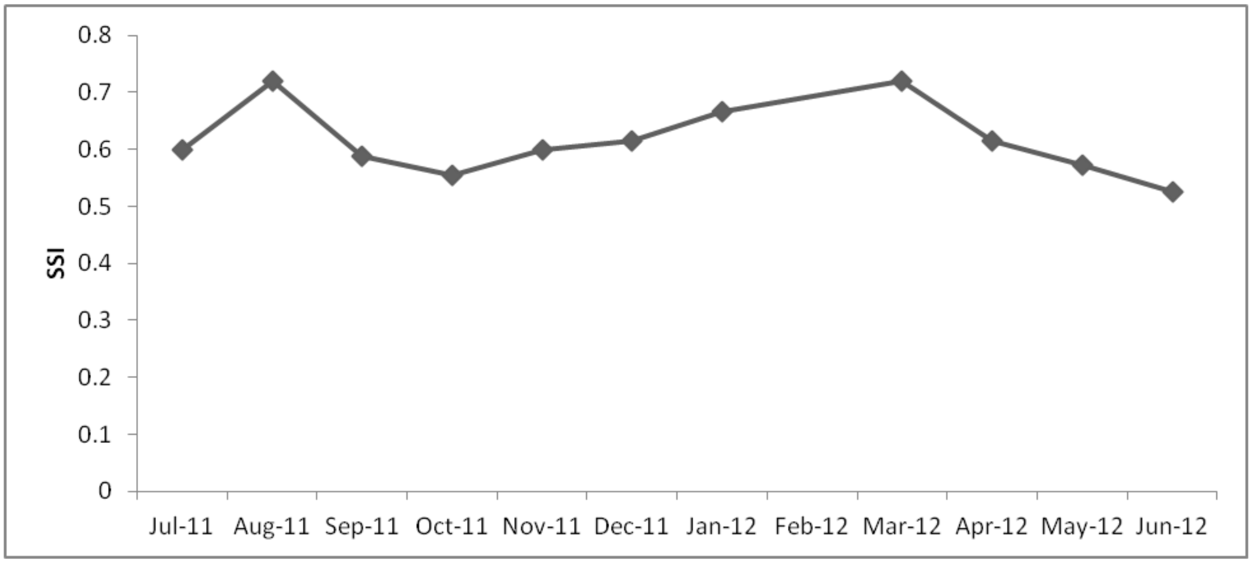


Figure 37a. Sørensen similarity index (SSI) comparing the Island Ponds with the adjacent reach of Coyote Creek. The SSI only operates on a species/presence or absence.

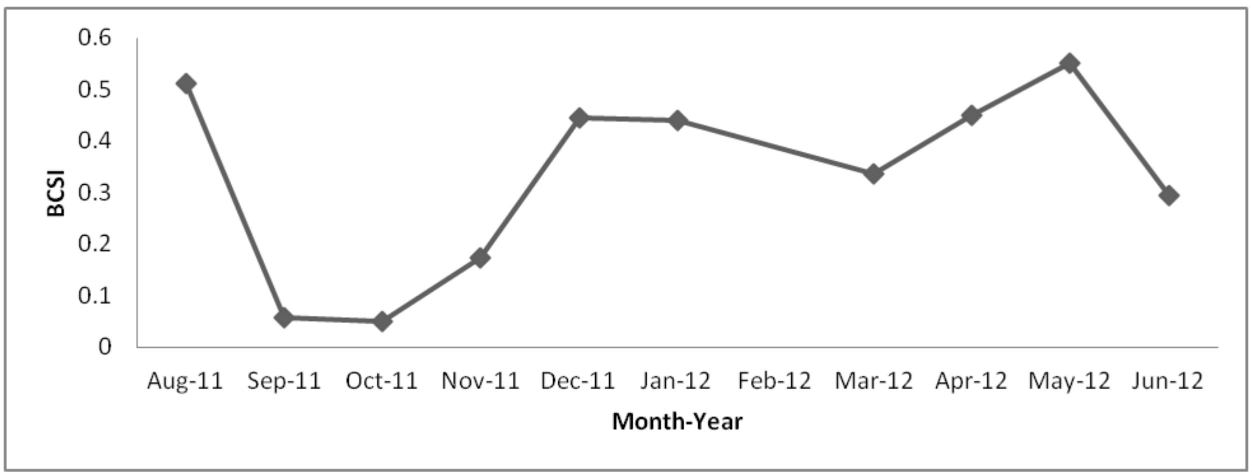


Figure 37b. Bray-Curtis similarity index (BCSI) comparing the Island Ponds and the adjacent stretch of Coyote Creek. The BCSI accounts for the relative abundance of species in each community.

Throughout much of the year, most of the fish present in the slough appear to utilize the restored habitat, resulting in communities that are fairly similar. The difference in fish communities that is observed in summer months is due in large part to the stressful conditions that exist in the Island Ponds during that time. Because the Island Ponds are large, shallow bodies of water, they get considerably warmer than the adjacent slough. The high temperatures, coupled with the large daily fluctuation in dissolved oxygen, create an environment that inhospitable to many fish species. However, these are extremely productive environments, and, as our invertebrate surveys have shown, the ponds have large numbers of potential prey items. Because of this, fish species that are capable of tolerating the abiotic stressors in these habitats reach extraordinary abundances (i.e., Pacific staghorn sculpin and threespine stickleback).

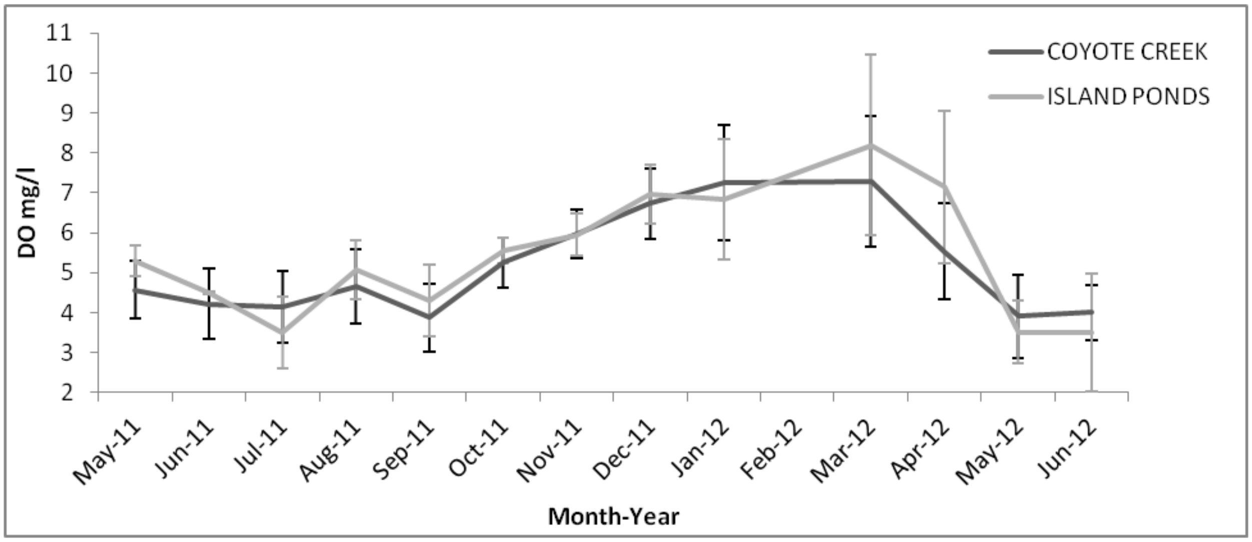


Figure 38a. Average monthly dissolved oxygen recorded in the Island Ponds and in Coyote Creek. Error bars are ±1 SD.

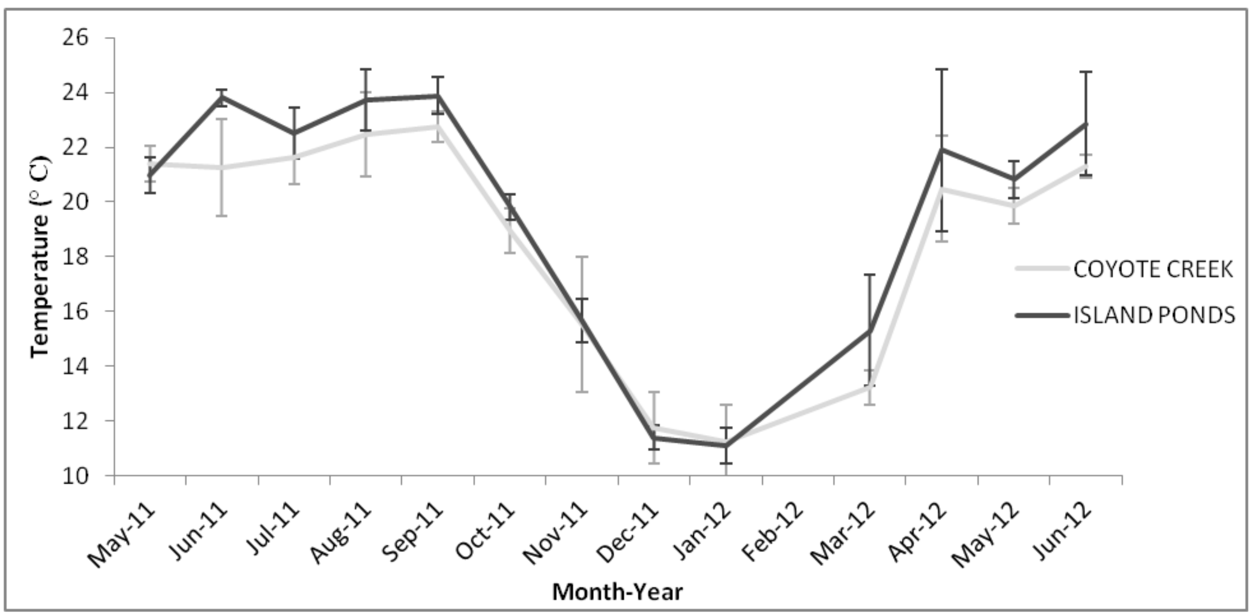


Figure 38b. Average monthly temperature recorded in Coyote Creek and the Island Ponds. Error bars are ±1 SD.

The fish species found in both Pond A19 and Pond A21 were similar throughout the year, which is reflective of the similar abiotic conditions in both habitats (i.e., high temperature and low dissolved oxygen in summer and relatively good water quality in winter). The only time when the fish species composition differed was following a runoff event in Coyote Creek in November, 2011 (Figure 39). This changed the salinity (an important abiotic factor) of Pond A19 more than that of Pond A21, resulting in a changed fish fauna.

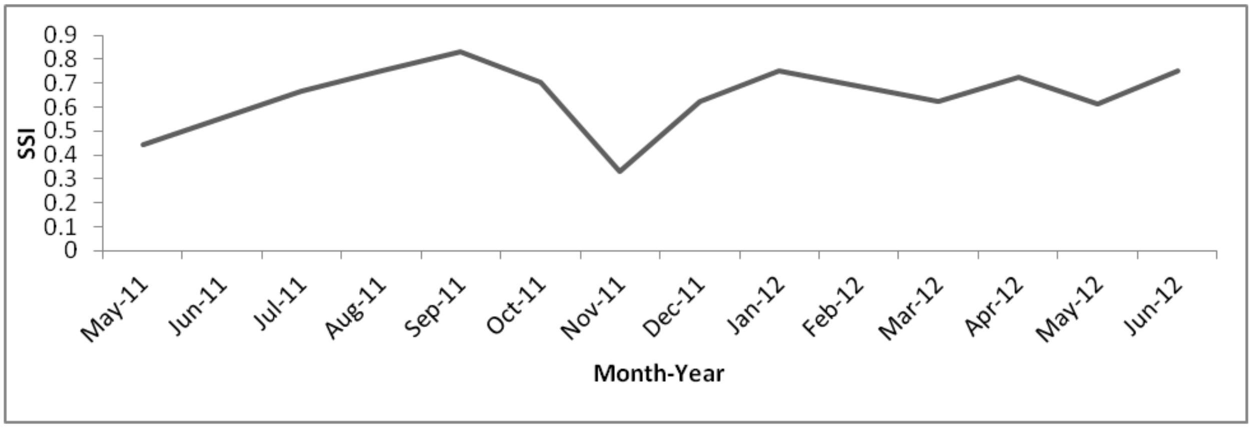


Figure 39. Sørensen similarity index (SSI) comparing Ponds A19 and A21 with the adjacent reach of Coyote Creek. The SSI only operates on a species/presence or absence.

In spite of similar species in both habitats, the dominant members of the two communities differed in summer and early fall (Figure 40), as indicated by a consistently low Bray-Curtis similarity index. The dominant member of the fish community found in Pond A21 was the Pacific staghorn sculpin, and the dominant fish species in Pond A21 was the threespine stickleback (see appendix).

Because of the relative elevations of the surface of Pond A19 and A21 and their position along Coyote Creek, A21 has become more vegetated and accreted more sediment than A19 (Brand et al. 2012). This slow habitat evolution creates more habitat for intertidal marsh specialists (such as Pacific staghorn sculpin) and less habitat for pelagic fishes (northern anchovies, threespine stickleback). The difference in the communities observed in A21 and A19 are reflected by this.

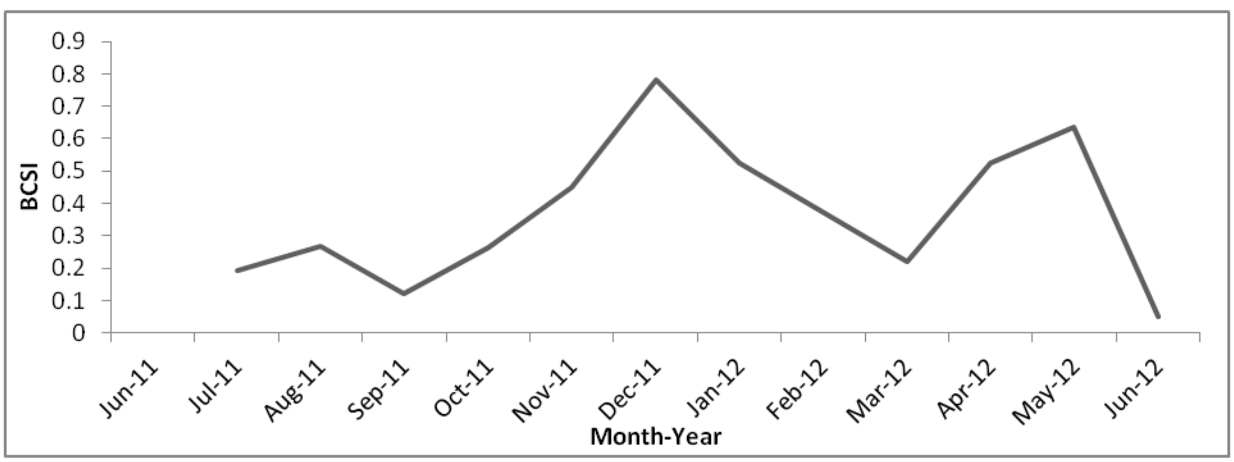


Figure 40. Bray-Curtis similarity index comparing the Ponds A19 and A21.

The two ponds increased in similarity in the late fall to spring months (October 2011 to April 2012). The two ponds were less similar in March 2012, when large numbers of Pacific staghorn sculpin began to recruit to the trawl inside pond A21. By April 2012, Pacific staghorn sculpin were also abundant inside A19, thus increasing the similarity index.

Sentinel Species Health Monitoring

Approach

Sentinel species health monitoring is an important and ecologically relevant approach for determining the effect of environmental stressors on a community of organisms. Although it is impossible to determine the precise factors contributing to the health of a free-ranging species found at a certain site, the use of an integrated approach incorporating somatic (whole body) condition indices, in concert with assessments of growth, nutritional status, disease status, and population abundance are good indicators of the general health of a species (Adams et al., 1989). The nutritional status of fish can mediate contaminant and disease impacts in susceptible species. Fish nutrition and growth may reflect overall food quantity, food quality, and availability of good habitat (Brinkmeyer and Holt, 1998; Gaspasin et al., 1998; Ashraf et al., 1993). Moreover, the presence of disease in wild fish populations is a significant health indicator because it represents the cumulative effects of multiple stressors and variables in the aquatic environment, many of which are unknown or poorly defined (Hedrick 1998). Seasonal, and interannual trends in adult abundance and the numbers of juvenile recruits has been used to track the population health status of many species in San Francisco Bay and is one of the most common metrics used to monitor fish (Honey et al., 2004). In this task, we monitor the health of a sentinel indicator species of salt-marsh habitat quality, the longjaw mudsucker (*Gillichthys mirabilis*), in restoration salt ponds and remnant marshes in South San Francisco Bay.

The longjaw mudusucker is a resident estuarine fish, ranging from Mexico to Humboldt Bay, California, USA, and is one of the most abundant fishes in high intertidal salt-marsh habitat (Desmond et al., 2000; Talley 2000; West and Zedler 2000). The Longjaw mudsucker depends on high intertidal creeks in marshes dominated by pickleweed [*Salicornia* (*Sarcocornia*)]. The fish reside within burrows in soft sediments and is the only fish species that can remain in intertidal creeks during low tide when the creeks completely de-water. The mudsucker can tolerate life out of water by having vascularized buccal cavities for uptaking oxygen from the air. Mudsuckers have a wide environmental tolerance, and are able to tolerate freshwater and salinities as high as 90-ppt for periods of a few days to a week, and temperatures from 9-35 C° (Lonzarich and Smith 1997, Moyle 2002). Longjaw mudsuckers are benthic consumers, most commonly eating bottom-dwelling invertebrates, such as amphipods, isopods, and small fish. Males will guard burrows and display their long maxillae, hence their common name, to attract females. Spawning occurs predominantly from late winter to early spring, with pelagic larvae settling to the benthos approximately two months after hatching. Juveniles (<80mm) spread out into many different habitats during summer, while adults tend to spend most of their lives in a single creek habitat, not straying more than a few meters from their burrows. With such a high degree of site fidelity, longjaw mudsucker completes its life cycle in a single marsh

(Yoklavich et al., 1992), making it an excellent candidate as a sentinel species of saltmarsh habitat quality.

The longjaw mudsucker has been used as a sentinel species of ecosystem health for saltmarsh habitats in San Francisco Bay, Tomales Bay, and Carpenteria Marsh in Southern California. The Pacific Estuarine Ecosystem Indicators Project (www.bml/PIEER.org) developed indicators of health for longjaw mudsucker with an emphasis on biochemical and ecological indicators in contaminated marshes. In San Francisco Bay, individuals from highly contaminated habitats exhibited poor liver quality, high levels of apoptosis (programmed cell death), and had large tumors on gonads (Anderson et al., 2006). Furthermore, populations in highly altered habitats had poor recruitment, low survival and lower abundances than more pristine marsh habitats (McGourty et al. 2009).

To assess the population status and general health of longjaw mudsucker inhabiting restoration ponds and adjacent remnant marsh habitats, we took an integrated approach by incorporating the monthly abundance of adult and juvenile recruits via catch per unit effort (CPUE) and estimated annual abundance and survival using a mark-recapture study from monthly minnow trap surveys. Health status was evaluated from monthly surveys by quantifying individual condition factor (length-weight measurements) and examining fish for structural deformities and incidence of external disease or parasite infection. Once a year in the fall, a subset of individuals (N= 8-10) were sacrificed and fish health was assessed from seasonal otolith growth, condition factor, hepatosomatic index (liver weight), incidence of disease and parasites, and proximate body composition analysis (% moisture, lipid-protein).

Study Areas

Alviso Marsh Complex

Pond A6 is a fully tidal pond with two breaches along Alviso Slough that were opened in November 2010. We chose 4 reference creeks (A6_O) along the remnant marsh outside the second northernmost breach to the pond. Initially, our first creek occurred where the breach was made, and we were forced to abandon this location. This area is characteristic of a remnant marsh that was altered by pond formation, with a levee built at the uppermost edge. Creek habitats are relatively intact, with short meandering reaches creating steep undercut banks which provide habitat for the longjaw mudsucker. Creeks are 30-40 meters in length and average a depth of 1.5 meters. The marsh plain (A6_I) is dominated by pickleweed with small patches of cordgrass growing on the marsh plain. Inside A6, the margins of the borrow ditch are forming pickleweed marsh; however, creek formation has not yet occurred.

Pond A8 (A8_I) is a managed pond, and is tidally muted from June 1 to November 30, with the water levels dictated by flood-control during winter months. Depths are usually between 1-3 meters. The pond is surrounded by rip-rap levees with very little pickleweed marsh. One small patch of pickleweed occurs at the old boat launch just north of the tide gates; however, this area is de-watered approximately half the year due to fluctuating water levels, rendering this location as a long-term study site difficult. We chose three lines (~30m length) along the southeast levee along the road, and when inundated we sampled the pickleweed marsh adjacent to the boat launch east levee. In May 2012, we began sampling just outside the tide gate along the edge to monitor for recruitment of juvenile longjaw mudsucker.

Pond A21 was the most extensively surveyed breached tidal salt pond, since it has the highest marsh plain and has pickleweed filling in much of the marsh plain with pockets of cordgrass occurring as well. We have sampled extensively along the borrow ditch edges (east, west, and north levees), along the inside of the large slough forming within the middle of the marsh, and along the marsh plain along the northeastern edge. Here we identified four reference creeks of about 60-meters (A21_I) length with pickleweed beginning to line the banks. We began consistently sampling these locations in May 2012. Sites within the interior of the marsh plain did have ample populations of longjaw mudsucker; however, access to this area was very limited and navigation has been dangerous. Because of the difficulties associated with access, we decided not to continue sampling the interior of the marsh plain. We selected five creeks outside the northern levee (A21_O) along Mud Slough as our remnant pickleweed marsh reference site. The creeks here are only about 10 meters in length and less than one meter in width.

Ponds A19 and A20 were sampled extensively in the first year of the study, and catches were sporadic, but were relatively high in the summer, averaging 1-3 per trap when juveniles were searching intertidal habitat. In both ponds no pickleweed marsh has begun to grow on the marsh plain and only a very narrow fringing marsh exists. Since very little habitat existed in these ponds, we decided to abandon A19 and A20 to focus more effort in A21.

Ravenswood

We chose three reference creeks along the outside of Pond SF2 (SF2_O), which average 30-60 meters in lengths and are less than one meter in depth. One of the three creeks is less than 0.3 meters in depth and is only inundated on the highest spring tides of the month. The first creek (nearest the Dumbarton Bridge) is a long meandering creek that is bifurcated into two first-order creeks and, as a result, is given twice the trap effort as the other two creeks. Inside SF2 (SF2_I) we chose 3 lines of about 30 meters in length along the east edge of the levee and the walking path, one before the breach and two after the breach.

Bair Island Marsh Complex

We extensively sampled outside Outer Bair Island, north side of Corkscrew Slough (OB_O) and Outer Bair Island (OB_I) beginning July 2010. We found very few longjaw mudsuckers given the extensive effort, and it was not until June 2012 that we began consistently (monthly) collecting mudsuckers in one creek outside of the easternmost breach, where a small patch of pickleweed marsh exists. We also sampled inside the restoration pond along the borrow-ditch edge and the marsh plain where pickleweed has been recruiting over the last year.

Eden Landing Mash Complex

We extensively sampled many pilot sites within and outside ponds E9_I, E8_I, E8X at the Eden Landing complex prior to breaching of these ponds in 2012. Initial sampling occurred in July 2010 when restoration ponds were drawn down for construction. We sampled the ponded waters adjacent to culverts and collected many longjaw mudsuckers; however, these sites were drained and bulldozed in the construction process. Two short creeks (~10m) along the Whales Tail Marsh (WT1) on the northwest corner outside the E9 breach were chosen as long-term sites. These sites have mature pickleweed marsh but are littered with trash from the bay. South of WT1 within the Whales Tail Marsh, we selected a second creek site with mature marsh and meandering channels. We have yet to establish consistent trapping sites inside the restoration ponds, but in June 2012 we successfully collected longjaw mudsucker from the northeast corner where water flows into E13 from E9, making this site a candidate for our long-term inside-pond site for Eden Landing.

Sampling Methods

Minnow Trapping

Collection of the longjaw mudsucker was accomplished using baited minnow traps in first-order channels (high intertidal creeks) of mature pickleweed marsh and along fringes of ponded water inside newly breached ponds (Figure 41).

Figure 41. (Left) Image of a first-order creek with minnow trap. (Right) a Gee Style Minnow Trap from Wildco.com.

The study began in July 2010, with sampling taking place approximately bi-monthly (July, August, October, November, and December) at several pilot sites to determine optimal locations for long-term study sites (Figure 42). We chose reference sites with remnant pickleweed marsh on the outside levees of restoration ponds, where at least 3 traps could be spaced evenly at approximately 5 meters apart along creek habitats to represent the source population for fish immigrating into restoration ponds. This was not possible for many sites as very few remnant marsh creeks remained, or were overgrown with cordgrass (*Spartina*) or tules (*Schoenoplectus*) (e.g., outside ponds A8, A19, A20, and A21; Figure 42). We searched restoration ponds for creek habitat and only pond A21 had pickleweed on the marsh plain where creek habitat was beginning to form; therefore, we selected fringing pickleweed along the borrow-ditch edges as test sites for most pond sites. Several sites were only sampled once or infrequently during the pilot period due to no catch or difficulty of access.

Figure 42. Map of all sample sites for minnow trapping of longjaw mudsuckers during the pilot phase. Sites labeled as _O represent reference locations outside restoration ponds in adjacent remnant *Salicornia* (i.e. pickleweed) marsh, while sits labeled as _I are sites within the restoration ponds. Blue dots show different creek sites.

Study Design

We selected long-term study sites at several restoration ponds that provided the opportunity to monitor abundance trends of longjaw mudsucker within restoration ponds and in reference remnant pickleweed marshes immediately outside restoration ponds (Figure 43).

Figure 43. Monthly survey sites (top left) Pond A8, (top right) A21, (bottom left) SF2, and (bottom right) A6.

We selected 3-5 replicate creek habitats per site. Each site was sampled with 1-5 baited minnow traps (depending on creek length) for a minimum of 12 hours overnight during the full-moon spring tide, when the highest monthly tides occur. Monthly sampling began in May 2011 and has been ongoing at ponds A6, A8, and A21 in the Alviso Marsh Complex and at SF2 at Ravenswood (Figure 42). Quarterly sampling has been occurring at Outer Bair Island and the Eden Landing Complex because of overall low catch. All fish species collected were counted and measured for standard length, and all invertebrate taxa were identified to species and enumerated. All longjaw mudsucker were weighed, sexed, and inspected for the presence of any morphological deformities, infections, and parasites (microsporidia and external parasites) (Figure 44).

Figure 44. (Top) Longjaw mudsucker with an abnormally developed right maxilla. (Middle) longjaw mudsucker with an infection of the micrscoporidian parasite (yellowish spots on the head). (Bottom) microscopy image of the microsporidian parasite *Kabatana* sp.

Abundance Trends

A monthly abundance (catch-per-unit-effort, CPUE) index was calculated by averaging the number of longjaw mudsucker per trap (1-5 traps) for each creek (3-5) and then averaging the mean catch per trap across the replicate creeks for each site (A8, A6_I, A6_O, A19-21_I, A21_O, SF2-I, SF2_O, Bair Island, and Eden Landing). The nested design, with replicated traps per creek and replicated creek per site, allows for accounting of spatial variation within a site. We calculated the monthly abundance index for adults, (>80mm) and juvenile recruits (<80mm standard length). Comparisons for adults and juveniles were made across all sites (ANOVA) and between site types (inside restoration pond vs. outside the pond in remnant marsh). The lengths of longjaw mudsucker at each site where compiled into length-frequency histograms using Origin 8.5.1 to allow comparisons of the size structure between sites and years.

Mark-Recapture

We conducted a mark-and-recapture study using the sentinel species longjaw mudsucker at sites in the Alviso Marsh complex (ponds A8, A6, A21, A20 & A19), the Ravenswood complex (SF2), Eden Landing (Whales Tail Marsh and E9), and at the restoration outer Bair Island pond to estimate abundance and survival rates. Initial marking began in May 2011 and was concluded in July, 2012. We conducted monthly minnow trap surveys at all sites during this period to recapture tagged individuals. During each survey, captured longjaw mudsuckers were measured to the nearest 1 mm (standard length), sexed (adults only >80mm SL), weighed (wet weight 0.1g), assessed for deformities, the presence of microsporidian parasites was noted, and (if untagged) injected with a Northwest Marine Technologies alpha numeric tag (Figure 45). During subsequent surveys, recaptured fish were measured as above and the unique tag identification number recorded.

Figure 45. Longjaw mudsucker with an alpha numeric tag.

Marking dates and the numbers of tagged fish varied among site in association with the numbers of individuals captured monthly. For the sites A6_O and SF2_O marking began in May 2011 and continued monthly through July 2012, while site A21_O began in October 2011 and A21_I began in November 2011 and continued through July 2012 (Table 1). Due to the theft of field journals and a laptop computer from our laboratory, data for marked individuals was lost for the months of Jan-April 2012. However, tagged individuals first captured during this time period were determined based on recapture site and the sequence of individual alpha-numeric tags. For abundance and survival estimates we pooled January to April for analysis.

Sites	5/6/2011	6/18/2011	7/2/2011	7/15/2011	7/17/2011	8/4/2011	8/16/2011	9/12/2011	10/10/2011	11/10/2011	12/10/2011	1/1/2012	2/2012-4/2012	5/5/2012	6/3/2012	6/29/2012	6/30/2012	7/1/2012
A6_O	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
A6_I			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
A8_I								●	●	●	●	●	●	●	●	●	●	●
A19_I	●			●		●		●		●								
A20_I	●	●		●		●		●		●								
A21_O									●	●	●	●	●	●	●	●	●	●
A21_I										●	●	●	●	●	●	●	●	●
SF2_O	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
SF2_I						●			●	●		●	●	●	●	●	●	●
Eden	●	●	●			●			●	●				●	●			●
Bair	●		●			●				●								

Table 1. Minnow trapping sites and sampling dates for mark-recapture study, regardless of whether longjaw mudsuckers were captured. Each black dot represents a sampling event.

Abundance was estimated using a closed population capture-recapture model (Higgins model) in program MARK (White and Burnham 1999). In this model, the population abundance is estimated using a full maximum-likelihood probability approach with the following parameters: p_i is the probability of first capture, c_i is the probability of recapture conditional on having been previously captured and tagged, and N is the abundance. The closed population model assumes the population of interest is closed to immigration and emigration during the sampling period and no births or deaths occur. We fit models with the parameters for the probability of capture p_i and recapcture c_i being constant over time and with a variable time component. However, a fully variable model is only possible when the final p_i of the survey is made equivalent to the final c_i , thus only three models rather than four were examined. Model fits were assessed with Akaiki's Information Criterion (AIC), which compares the model likelihood and accounts for the number of parameters estimated (Kutner et al.2004).

Annual survival and capture probability was estimated for longjaw mudsucker from monthly mark and recapture at four sites (A6_O, SF2_O, A21_O and A21_I). Marking dates and recaptures occurred as described above. Survival was estimated using the Cormack Jolly Seber (CJS) model in program MARK (White and Burnham 1999). In this model, survivial (ϕ, phi) and capture probability (*p)* from consecutive surveys were estimated from marked and recaptured individuals using the maximum likelihood probability. The CJS model assumed survival and catchability probabilities for all individuals (marked and unmarked) were the same. We fitted models with both constant ϕ and *p* and time-varying ϕ and *p* that resulted in four models fit. Model fits were assessed with AIC.

Health

To assess the health of the longjaw mudsucker, we examined all fish collected in minnow traps from the monthly surveys for condition factor and the incidence of infection and parasitism. We also collected a subsample of up to 10 individuals from several sites (A6_I, A6_O, A8, A21_O, A21_I SF2_O and E9_O) during fall of 2011. Fish were euthanized with an overdose of MS-222 (Trimethyl sulfate), numbered individually, and frozen in dry ice. Upon returning from the field, fish were stored in -20^{o}C. Necropsies were conducted within two weeks of returning from the field. Standard length (1-mm) and wet weight (0.1g) were recorded and were of the presence of internal parasites and external deformities was noted. The liver was dissected whole and weighed, allowing for the computation of the hepatosomatic index. Gonads were also removed and weighed when present. Otoliths were dissected and stored in individual labeled trays for growth analysis. All contents of the body were returned to the individually labeled bags and stored at -20^{o}C for proximate analysis.

Condition Factor

The wet weight of each individual was measured in the field with an Acculab EC-411 portable balance (0.1g). The condition factor was calculated using Fulton's Condition Factor Index. This was done for each longjaw mudsucker collected from monthly surveys (May 2011 to July 2012). In addition, we measured condition factor in the lab for the subsample collected for otoliths and proximate analysis.

Equation 6: Fulton's Condition Factor Index (FCFI)

FCFI = $weight\,\frac{10,000}{length^3}$

Hepatosomatic Index

The wet weight of liver was weighed for the subsample of longjaw mudsucker, the hepatosomatic index was calculated as follows:

Equation 7: Hepatosomatic index

Hepatosomatic index $= \frac{liver\ weight}{length^3}10000.$

Disease and parasites

All longjaw mudsuckers were examined in the field for the presence of microsporidia. The degree of infection was quantified with an infection scale of 1 to 3, with a score of 1 representing individuals with a few distinct nodules located around the abdomen and the head, a score of 2 representing many nodules located throughout the body, and a score of 3 for individuals with extensive infection and in an emaciated state. External gill parasites and hookworms were also noted in the field. Skeletal deformities were also noted for body parts, but no ranking score was conducted.

Proximate Analysis

Proximate analysis refers to the measurement of the major constituents of the body, including moisture (water), lipids, proteins, minerals, and carbohydrates, and is reported as percentage of the total body weight. Whole carcasses, minus the otoliths, were freeze-dried in a furnace for approximately 7 days and weighed. The dried carcass was then ground to a powder and baked in a drying oven at 120^{o}C for 72 hours to remove the residual carbon ash. Ash-free samples were weighed and used as a proxy for the remaining lipid and protein content.

Otolith Growth

Otoliths were mounted onto glass slides with Crystal Bond thermoplastic resin in the sagittal plane, ground to the core on both sides with wet-dry sandpaper, and polished with a polishing cloth and 0.3-micron polishing alumina. Otoliths were digitized with a digital camera at a magnification of 100X. Otolith increments were enumerated, and the distance from the core to each daily ring was measured using Image-J NIH software. Growth rates were quantified using several approaches. The size at each daily increment was estimated using the Biological Intercept Model (BIM) method previously developed for delta smelt (Hobbs et al. 2007). Seasonal growth rates were quantified from the settlement check mark, which is formed when the larva transitions from the pelagic to benthic environment approximately two months post hatch, to the edge of the otolith or the point at which daily increment formation was difficult to interpret.

Results

Abundance Trends

The abundance Index (CPUE) of longjaw mudsucker varied considerably on a monthly and seasonal basis, with the months of June-August (summer) having the highest abundance and the winter months the lowest abundance (ANOVA: MS 37.5, df=26, F-Ratio=8.9,5 p <0.001 (Figures 6-9). The seasonal abundance trend did not vary between years (2010-2012) with high abundance in summer months and lows in winter months. Abundance varied between sites, with A6_O having the highest abundance and A8 the lowest (ANOVA: MS 76.9, F-Ratio =12.9, df=6, p <0.001); however, sites where longjaw mudsucker populations were not persistent, such as Outer Bair Island and Eden Landing were excluded from the analysis . Sites inside restoration ponds tended to have much lower catch (ANOVA: MS 227, F-Ratio=33.7, df=1, p<0.001) compared to outside remnant marsh sites, although sites inside A21 (A21_I) and A6 (A6_I) had equivalent CPUE compared to outside reference sites (A6_O and A21_O) in summer months, exceeding an average of 3 adults per trap. Abundance was lower for ponds with a muted tide stage (A8 and SF2_I) compared to ponds that were fully tidal (ANOVA: MS 324.8, F-Ratio=51.2, df=1, p < 0.001). The abundance of longjaw mudsucker increased during the surveys for adults at sites A6_O and A21_I and A21_O while declining at A6_I; they also increased during 2011 at SF2_O and A8, but then declined in 2012.

Recruitment of Juveniles

Longjaw mudsucker recruitment (CPUE of fish <80mm SL) varied among inside-outside restoration pond comparisons (ANOVA: MS 56.4, F-Ratio=15.2 df=1 $p<0.001$) and between sites in 2011 and 2012 (ANOVA: MS 21.4, F-Ratio=6.1 df=6 $p<0.001$) (Figures 46-49). Recruits were observed at all sites but were in greater abundance at sites outside restoration ponds. At stations A6_O and SF2_O, recruits were observed during each survey, and at A21_O they were observed at all but four surveys. Recruits were most abundant during the summer months (May-Aug) at all sites, declined during the fall months ,and were rare during winter. This pattern reflects the reproductive timing, and the subsequent mortality and recruitment into the adult size class. In 2011, the abundance of recruits was similar among all sites, averaging approximately 2 fish per trap. In 2012, the CPUE for recruits was higher at all sites than in 2011, and were in greater abundance inside ponds A6 (A6_I) and A21 (A21_I) relative to outside A6 (A6_O) and A21 (A21_O). The abundance of recruits was similar to adults at most sites and surveys; however, the abundance of recruits was greater at A6_I in August 2011 and July 2012, at A21_I in July and August 2011, at A21_O in July 2012, at SF2 in June and July 2011, and in July 2011 at A8.

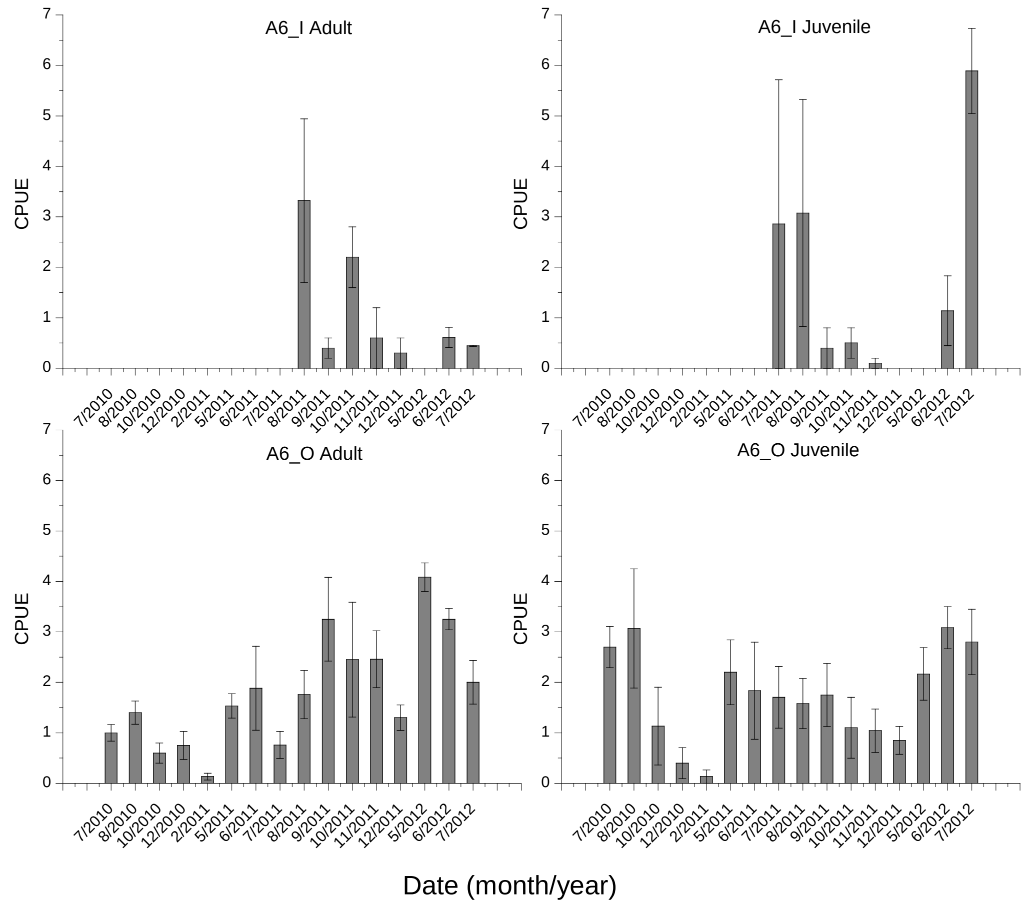


Figure 46. Monthly CPUE for the sites A6_I and A6_O for adult and juvenile longjaw mudsucker. Error bars depict 1 SE.

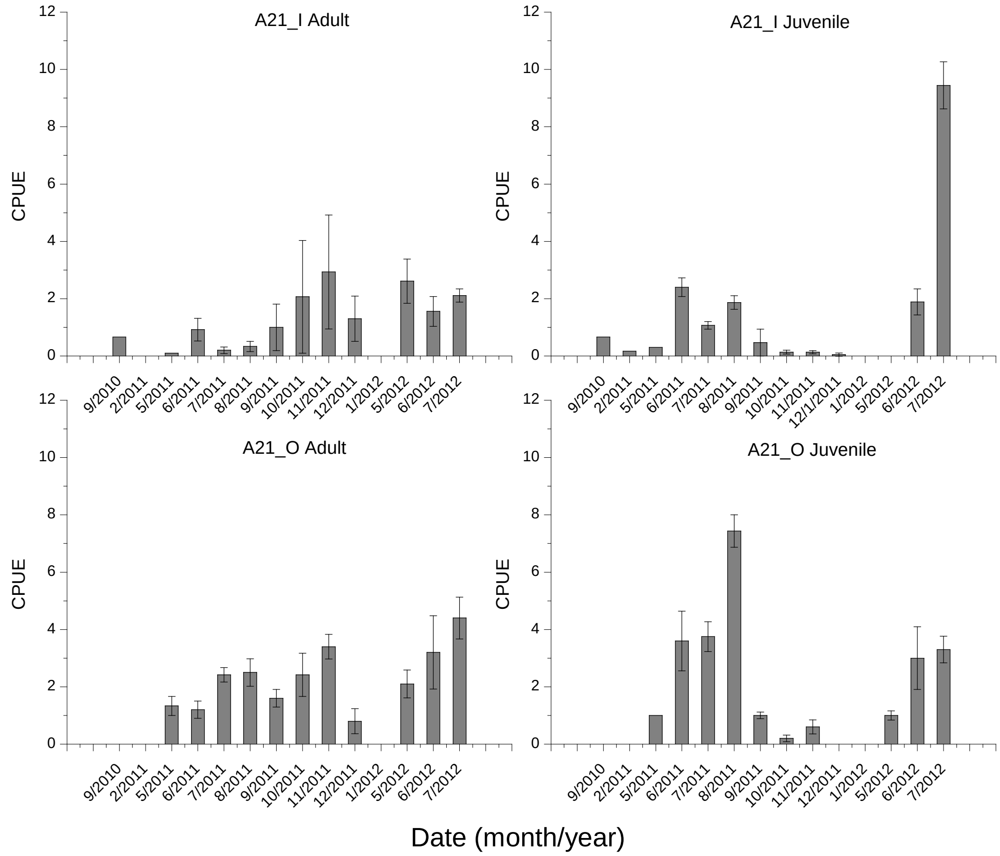


Figure 47. Monthly CPUE for the sites A21_I and A21_O for adult and juvenile longjaw mudsucker. Error bars depict 1 SE

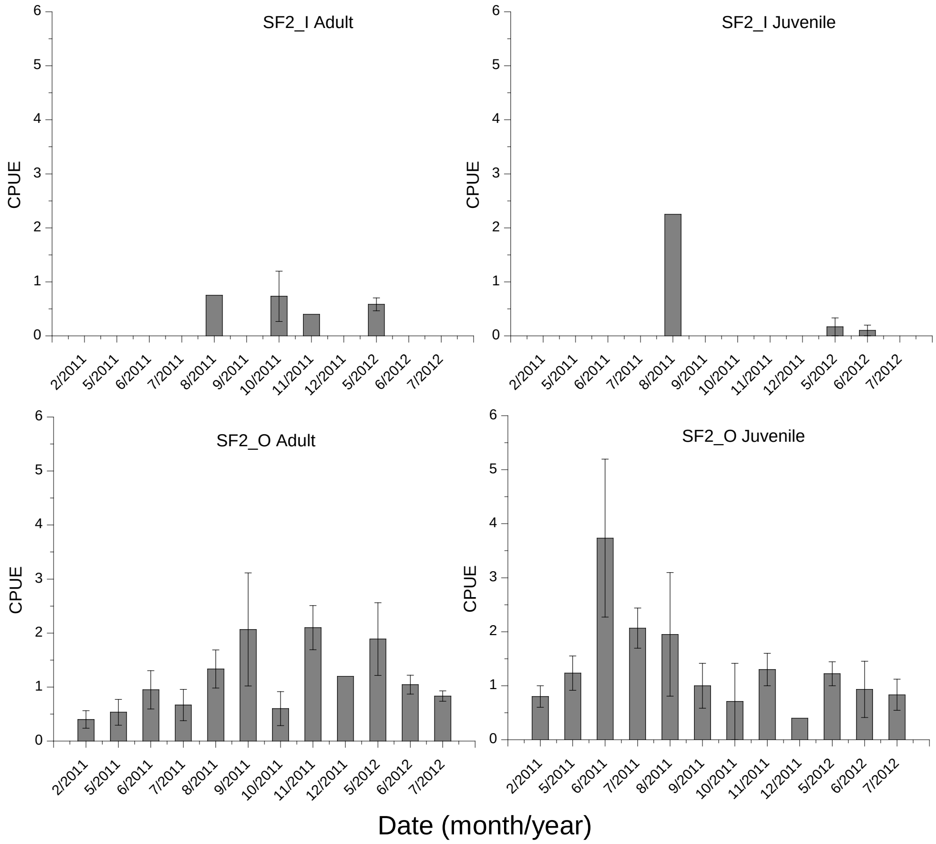


Figure 48. Monthly CPUE for the sites SF2_I and SF2_O for adult and juvenile longjaw mudsucker. Error bars depict 1 SE.

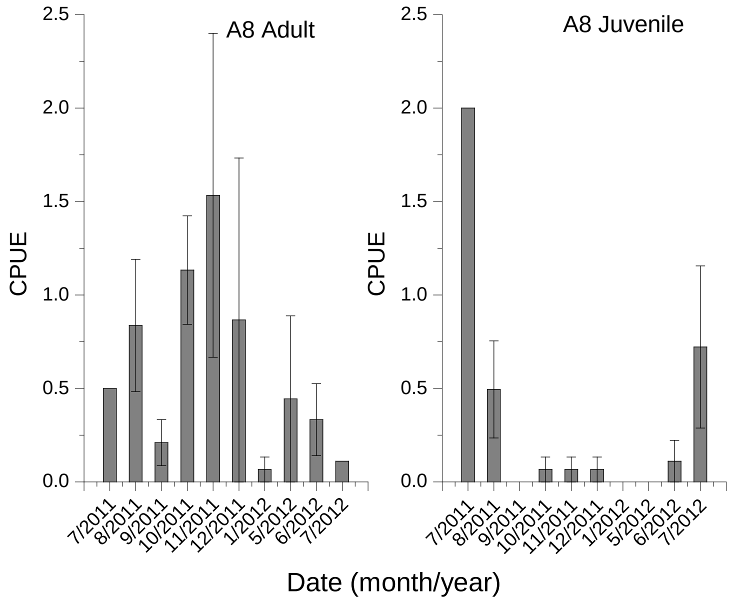


Figure 49. Monthly CPUE for the sites A8_I for adult and juvenile longjaw mudsucker. Error bars depict 1 SE

Length Frequency

The timing of peak recruitment varied by one month between sites and years, with new young-of-the-year (YOY) recruits (45-60 mm SL) entering the minnow traps in May for sites A21_I (Figure 10) and A6_O for 2011 (Figure 51), while sites A21_O (Figure 50) and SF2_O (Figure 12) had recruits first appearing in June. Sites A6_I (Figure 51) and A8 (Figure 53) did not receive these small size classes until July 2011. With length-frequency histograms, the change in size of the YOY recruits can be followed from each monthly survey. Recruits at all sites had reached a length of ~90 mm by December of their first year. Adults did not appear to grow as quickly as YOY recruits, and fish beginning the year at a length greater than 90 mm reached a length of ~110-mm SL by December, and fish greater than 120-mm SL were rarely observed . Growth rates approximated from length-frequency changes were consistent with otolith growth data from this study and from our previous work in central San Francisco Bay and Tomales Bay (Hobbs, unplublished data). YOY grew approximately 10-15 mm per month in the summer up to a length of 90 mm, at which point growth slowed to less than 10 mm a year, with fish reaching a maximum size of 135 mm at an age greater than 4 years. Site A6_I was first breached in November 2010, and, in the following spring, recruits began to utilize this habitat and appeared to grow rapidly, reaching greater than 90 mm by October, although they were not found in November or December 2011. We began catching fish again in June 2012; however, very few individuals from the 2011 cohort were observed. The range and variation in length distributions were often greater for sites outside restoration ponds compared to sites inside restoration ponds; however, the length variation within A21 (A21_I) was larger then the adjacent reference site (A21_O) (or any other site) from May to August 2011.

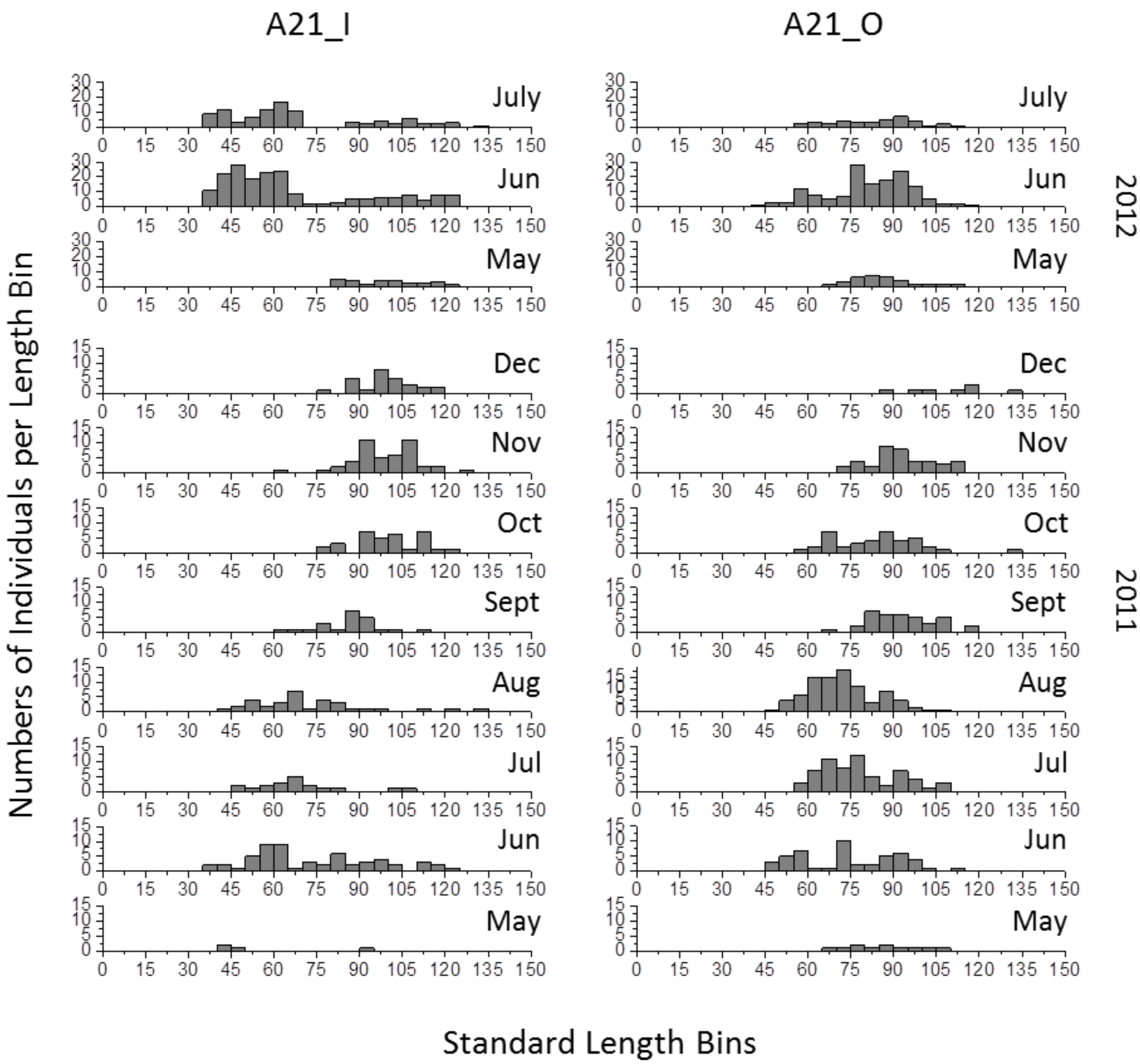


Figure 50. Length-frequency (number of fish per length bin) distributions for longjaw mudsucker collected from monthly minnow trap surveys at sites A21_I and A21_O for May-Dec 2011, and May-July 2012.

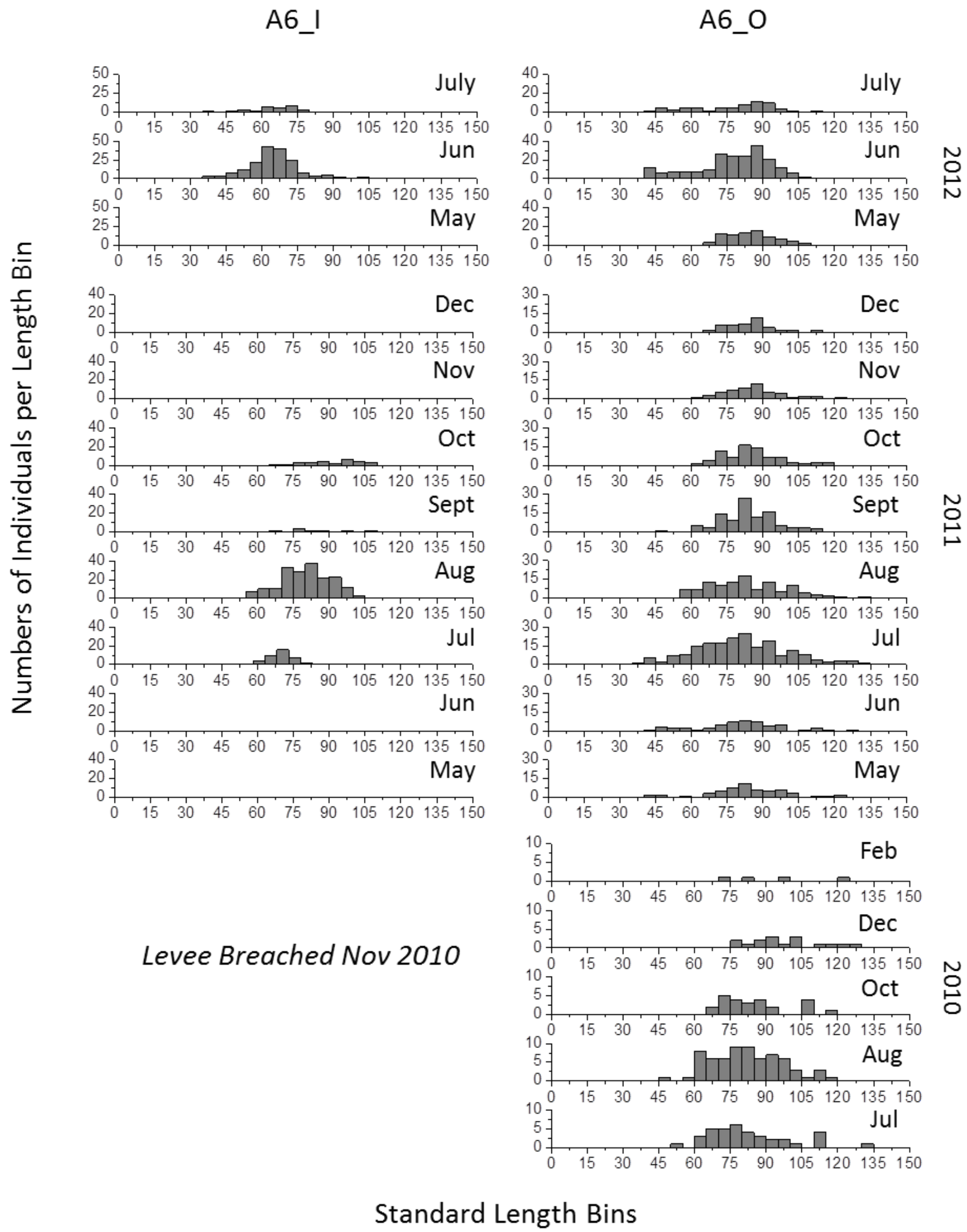


Figure 51. Length-frequency (number of fish per length bin) distributions for longjaw mudsucker collected from monthly minnow trap surveys at sites A6_I and A6_O for the pilot period Jul-Feb 2010-2011, May-Dec 2011, and May-July 2012.

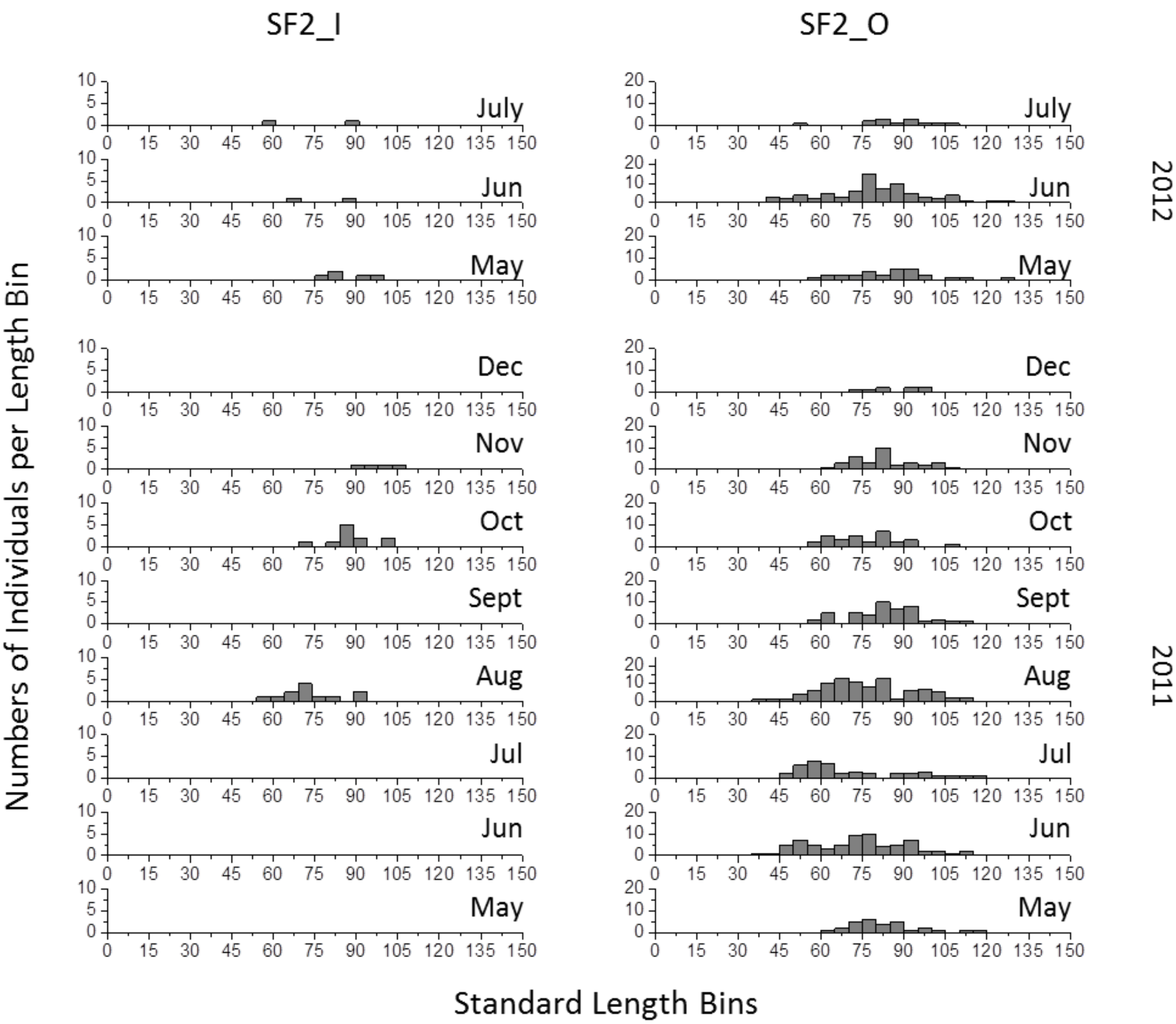


Figure 52. Length-frequency (number of fish per length bin) distributions for longjaw mudsucker collected from monthly minnow trap surveys at sites SF2_I and SF2_O for May-Dec 2011 and May-July 2012

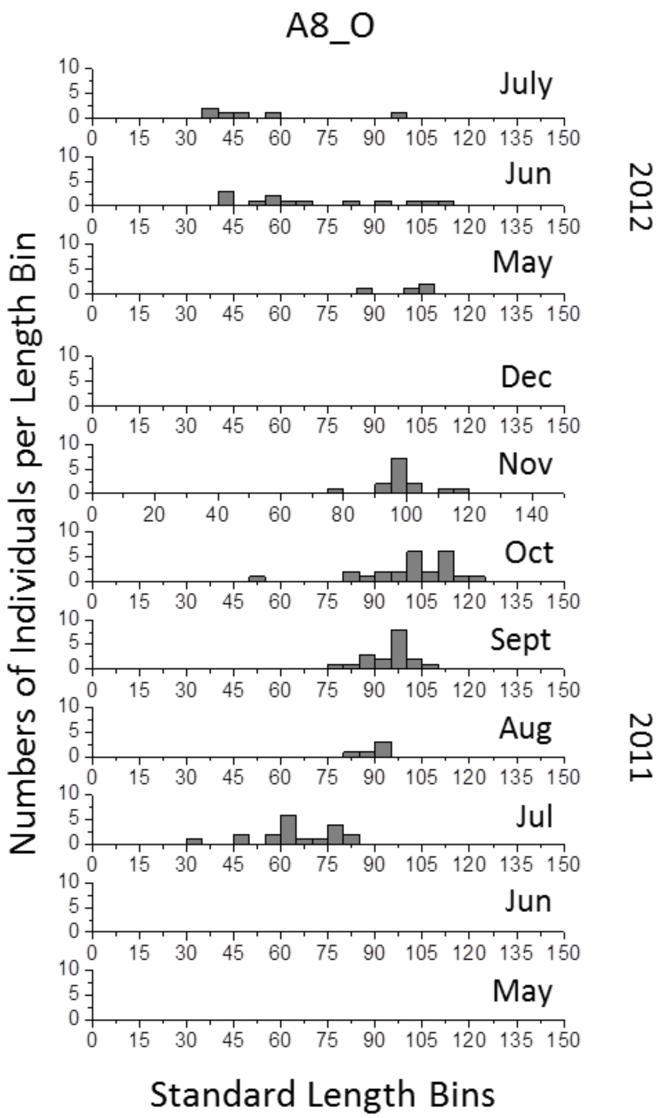


Figure 53. Length-frequency (number of fish per length bin) distributions for longjaw mudsucker collected from monthly minnow trap surveys at site A8 for May-Dec 2011 and May-July 2012

Annual Abundance Estimates

The numbers of tagged and recaptured individuals with unique capture histories varied between sites and years, with the A6_O site having the largest number of tagged and recaptured individuals in both 2011 and 2012. Note that many individuals at all sites were recaptured more than once. Table 2.

	2011			2012	
Sites	Tagged	Recaptured		Tagged	Recaptured
A6_O	446	104		205	73
SF2_O	300	26		64	18
A21_O	67	28		100	52
A21_I	62	7		192	33

Overall, the model with time-varying first capture probability(*p)ᵢ* was the model best fitting the data for each site and year except for site A21_O in 2011, reflecting the seasonal patterns of activity or abundance of the fish, with activity and catch per unit effort being greater in summer than winter months (Table 3).

	A6_O		A21_O		A21_I		SF2_O	
Model Type	2011	2012	2011	2012	2011	2012	2011	2012
Constant first capture	-1042.76	-544.20	47.41	-86.37		-1021.50	-1071.02	-34.30
Time varying first capture	-862.78	-514.21	35.15	-65.37		-888.33	-931.96	-28.65
Differing first capture and recapture	-693.70	-509.81	138.56	-63.22		-862.51	-716.20	-26.78

Table 3. AIC for closed-capture models fit to mark-recapture encounter histories. Greater values (more positive and more negative) depict the best fit to the data given the number of parameters estimated.

Annual abundance estimates varied among sites, with the high abundance occurring at A6_O (N = 783) and SF2_O (N = 863) and low abundance at A21_O (N = 89) for 2011 (Figure 54). No estimate was calculated at A21_I due to the low numbers of recaptures. Annual abundance estimates for 2012 were calculated only for the May-July months at the four sites, as data was missing for the January-April months. The shorter time interval precludes directly comparing abundance between 2011 with 2012, however relative differences between sites within years could be used to assess abundance trends. Abundance was high for A21_I (N = 689), while A6_0 was lower (N = 308) and SF2 (N = 107) and A21_O (N = 106) were the lowest for the year. In 2012, abundance was much lower for SF2_O relative to the A6_O site, in comparison to 2011, suggesting abundance was likely much lower overall at SF2_O in 2012.

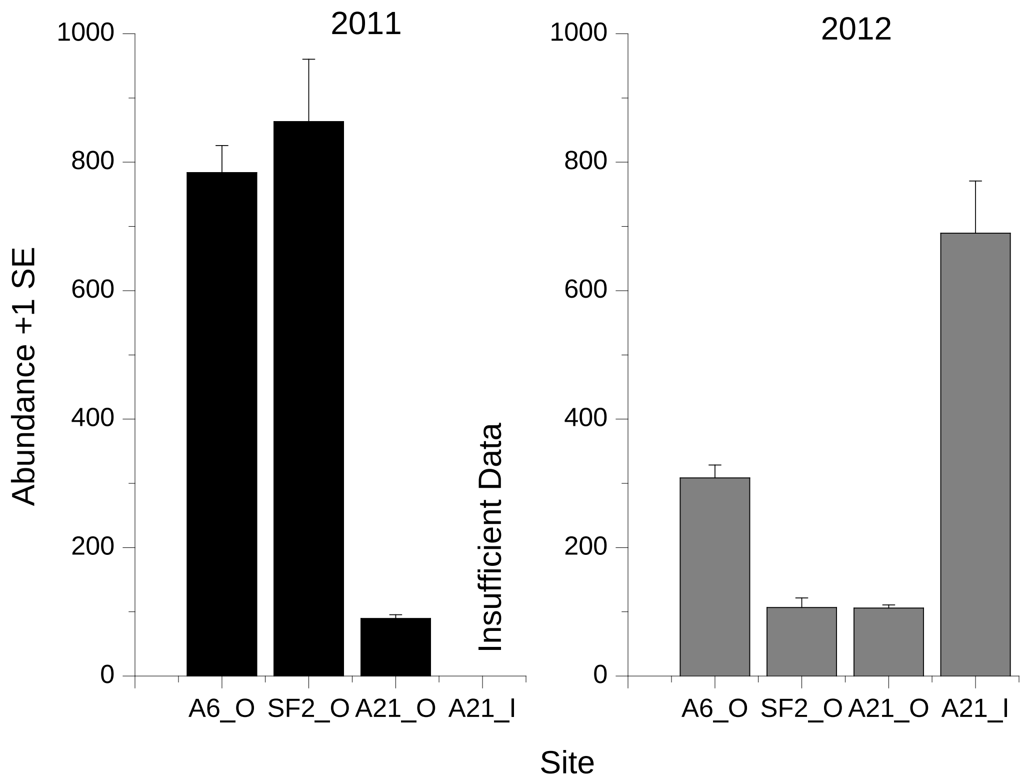


Figure 54. Annual abundance estimates from a closed capture model ± 1 standard error. Note for 2012 estimates include data for only May-July, while 2011 estimates are based on data from May-December.

Survival

At all sites, the models with constant survival were selected as the best-fitting model. Models with variable capture probability best fit all sites in 2011 (except A21_I, which was not calculated for 2011 due to low recaptures); however, constant capture probability provided a better fit to 2012 data. A constant survival probability model, suggests that for the annual scale, seasonal survival differences could not be detected, and again the variable capture probability reflects the seasonal abundance patterns. Survival probability varied from 0.48 at A21_I in 2012 to 0.73 at A21_O 2011 and did not vary statistically among sites. (Figure 55). Differences in parameter error likely reflect the sample sizes for each site and year.

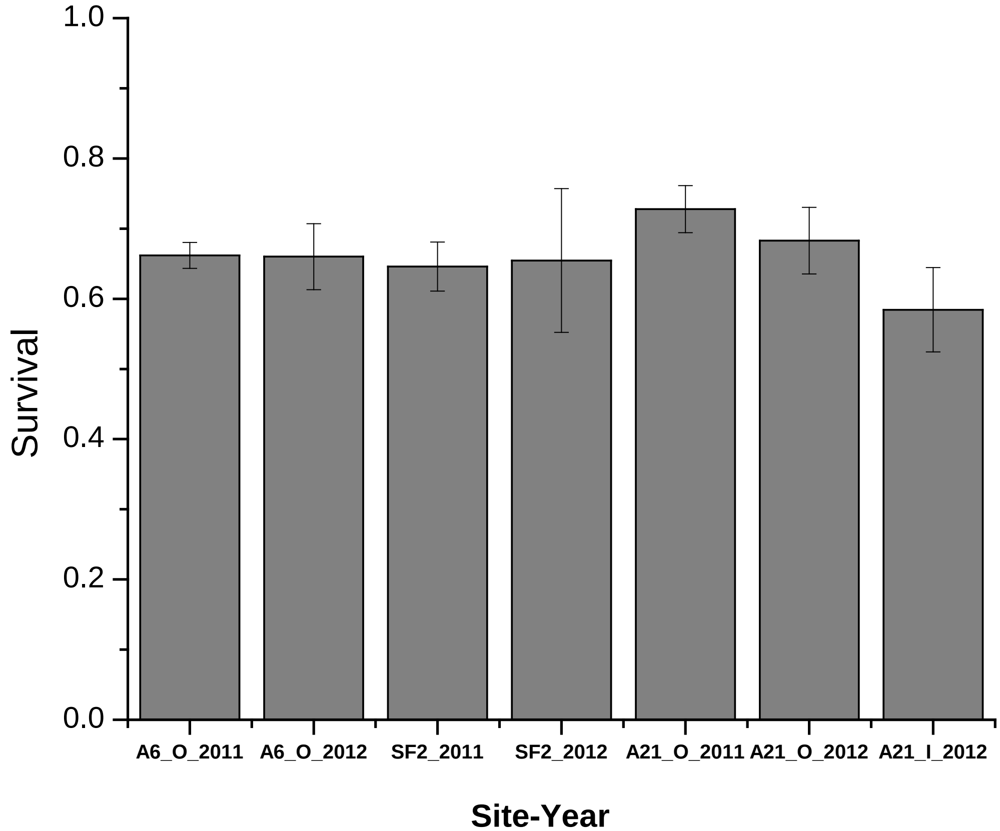


Figure 55. Survival estimates ± 1 standard error from Cormack Jolly Seber model.

Capture Probability

Capture probability was highest during the summer months (0.2- 0.6) and was lowest during the winter (<0.1) (Figure 56). Pond A6_O exhibited a higher capture probability during the summer months than the October to November period. Capture probability tended to be lower for SF2_O and ponds A21_O and A21_I. (Note that recapture probability for the latter two sites was only possible for the December 2011 to July 2012 period.)

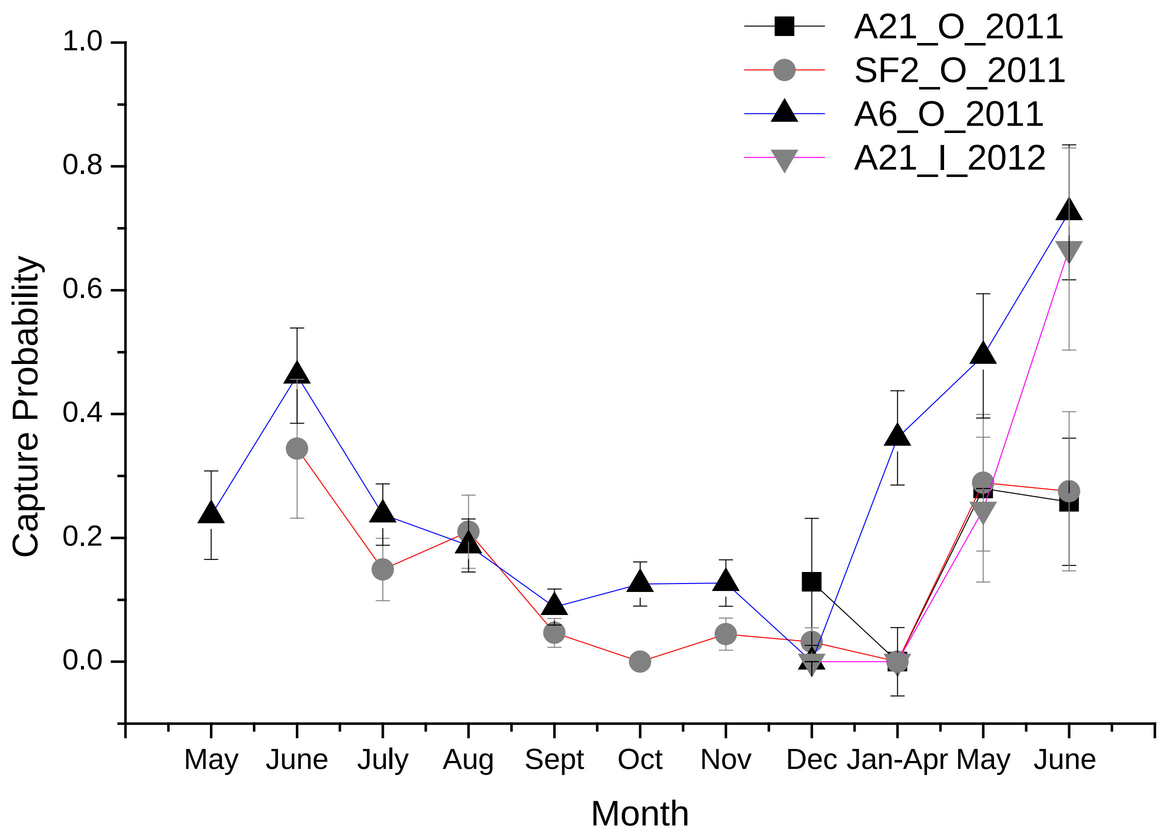


Figure 56. Monthly probability of capture derived from a Cormack Jolly Seber model. Error bars depict 1 standard error.

Condition

We measured the condition factor (Fulton's Index) for 3,135 longjaw mudsuckers collected during monthly surveys. Condition varied seasonally among all sites, with the spring months having a lower condition factor compared to all other months (ANOVA: MS=2.1, F-Ratio=10.4, df=3, p<0.001) (Figure 57). In comparing ponds, we did not find a difference among sites (ANOVA: MS=0.5, F-Ratio=2.2, df=4, p<0.65). Condition factor was higher inside restoration ponds compared to outside adjacent remnant marshes (ANOVA; MS=13.9, F-Ratio=69.1, df=1, p<0.001) and was higher in ponds with a muted tide stage compared to fully tidal ponds (ANOVA; MS=2.1, F-Ratio=10.4, df=1, p<0.001) (Figure 57).

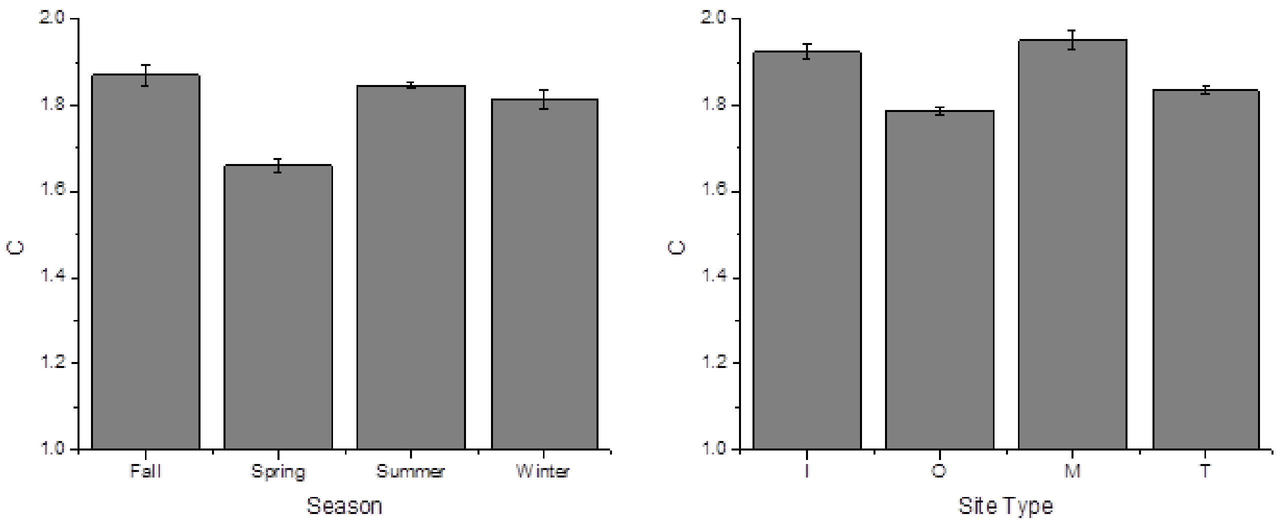


Figure 57. Condition factor for longjaw mudsucker collected during monthly surveys. (Left) season trends and (Right) different restoration types (I= inside restoration ponds, O= outside restoration ponds, M = muted tide-stage ponds A8 and SF2, and T = fully tidal ponds). Error bars depict 1 SE.

Otolith Growth

Growth rates estimated from otolith increment widths and back-calculated from the BIM ranged from 0.5mm/day at A21_I to 0.7mm/day at SF2_O. Overall, sites did not vary significantly (ANOVA: MS=0.034, F-Ratio=1.618, df=6, p=0.156), and no significant difference was found for the comparison between the inside of the restoration ponds compared to adjacent marsh habitats (ANOVA; MS=0.01, F-Ratio=0.028, df=1, p= 0.867) (Figure 58).

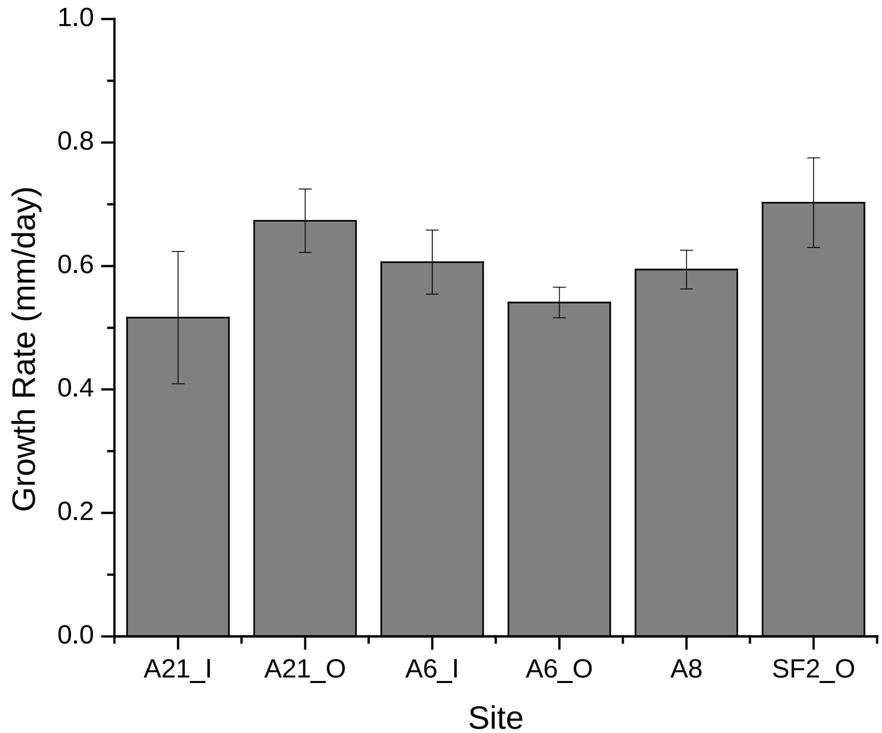


Figure 58. Summer otolith daily growth rate back-calculated from otolith increment widths from the settlement check to the edge of the otolith or the point at which daily increments were not visible. Error bars depict 1 SE.

Proximate Body Composition

The proximate analysis of body composition for % moisture and % lipid was variable between sites; however, we found no statistical significance (ANOVA: MS=0.034, F-Ratio=1.618, df=5, p=0.156), due to the large within site variation (Figure 59). Regardless of statistical significance, we did observe relevant patterns of variation with Pond A8 having the highest % moisture and lowest % lipid content of all the sites, while A6_O and SF2_O exhibited similar overall patterns. Condition factor was also not different between sites and showed considerable variation among individuals. Hepatosomatic index was generally lower at Pond A8 and SF2_O, but due to individual variation no statistical differences were found. All analyses failed to detect statistically significant patterns due to the high within site variation. The failure to detect a statistically significant pattern was likely due to low sample sizes with only 8 individuals analyzed per site. A small sample size was deliberately chosen to minimize the impact of removing individuals from small populations, where mark and recapture studies were being conducted.

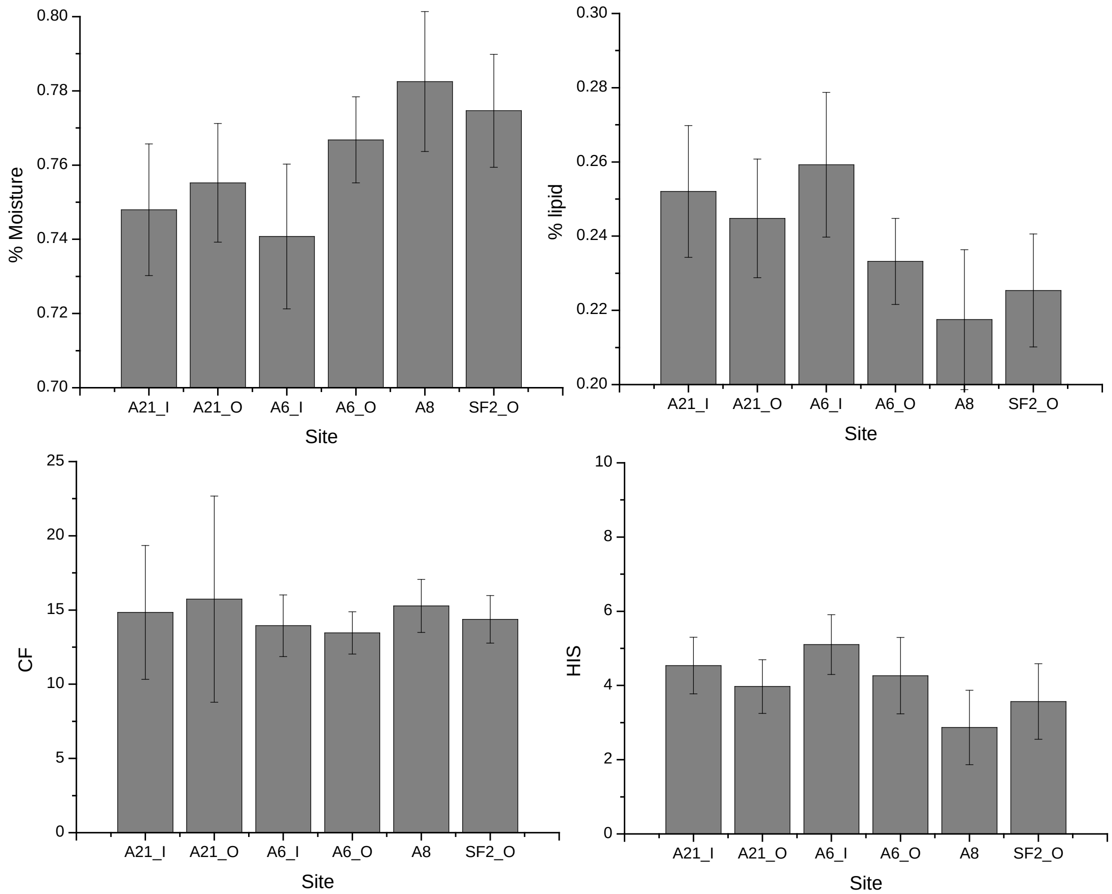


Figure 59. (Top-Left) The percent body moisture for a sample of 8 individuals collected in fall of 2011. (Top-Right) The percent lipid content, (Bottom-Left) Fulton's condition factor, and (Bottom-Right) the hepatosomatic index. All error bars a ±1 SD.

Disease and deformities

The incidence of the internal microsporidian parasite *Kabatana* sp. was low overall with a total of only 46 incidences out of the 3,135 longjaw mudsuckers examined. The sites outside A6 in the remnant pickleweed marsh had the highest incidence with 26 infected individuals, Pond A8 had 6 individuals, SF2_O had 7 individuals, A6_I and A21_O both had 3 individuals, and Outer Bair Island only had 1 individual. We also observed very few fish with visible deformities, with only 18 deformed individuals observed out of the 3,135 longjaw mudsuckers examined. Deformities observed included maxilla skeletal curvatures and eye hemorrhage. The site outside SF2 and the Ravenswood marsh had the highest incidence of deformities, with a total of 6 individuals, while ponds A8 and A6_O had 3 individuals, A21_I and A21_O had 2 individuals, and Eden Landing's pond had a single individual. No incidence of scoliosis or other structural deformities or other external parasites were observed.

Discussion

Monitoring the sentinel species population and individual health status has revealed that most restoration ponds have yet to provide permanent habitat for the longjaw mudsucker, an obligate intertidal pickleweed marsh specialist. At all but one restoration pond, the mean catch per unit effort and abundance was greater at reference sites in remnant pickleweed marsh habitats outside, than at sites inside restoration ponds. However, we did find that condition factors of fish occupying restoration ponds, including those managed for a muted tide regime, was better than remnant marsh sites. Pond A21 was the only pond that supported longjaw mudsuckers year round. In addition, Pond A21 has shown the greatest recovery of pickleweed and cordgrass, with large sections of marsh beginning to form in the interior of the pond and intertidal creek habitats beginning to scour. At most of the restoration ponds, pickleweed has begun to grow extensively along the leveed side of the borrow ditches, but very little vegetation has grown in the interior mudflats and no creek habitats exist. The longjaw mudsucker is a species that burrows into the bottoms and the vertical banks of intertidal creeks and remains in these habitats during low tides when these areas are dewatered. While the mudsucker has been found in deeper slough habitats at times, these observations are very rare, supporting the idea that this species depends on intertidal creeks to thrive. Based on our observations, it is likely that pond restorations will not support populations of adult longjaw mudsucker without extensive pickleweed marsh and creek habitats for this species.

The restoration ponds did receive large numbers of juveniles during the summer months when new recruits were seeking out intertidal creek habitats; however, very few individuals appeared to overwinter inside restoration ponds and recruit to the adult population the following year. Since, lonjaw mudsuckers can burrow into soft sediments, and the restoration pond sites provide an abundance of soft sediment habitat, it is not clear why these habitats do not support long-term residence of longjaw mudsucker. Predation may be an important factor explaining the low numbers of longjaw mudsuckers in restoration ponds. While burrowing into soft sediment would protect mudsuckers from predation by most piscivorous fishes, the major fish predators in this system are the leopard shark and bat ray, which can use electroreception to find prey buried in sediments, and most wading birds are adept at locating borrowed fish as well. Food abundance may also be a factor affecting the use of restoration ponds; however, condition factors for fish collected inside ponds was greater than sites outside ponds, which does not support food abundance as an explanation for low numbers inside restoration ponds.

A third, behavioral hypothesis also exists: longjaw mudsuckers simply may not prefer open mudflat habitat, and seek out intertidal marsh creek habitats, thus abandoning the restoration pond habitats that do not have proper habitat.

Individual condition and health metrics suggest that conditions for feeding and growth inside restoration ponds was satisfactory for the small number of fish collected there; however, at locations along Alviso Slough, other stressors may affect the condition of longjaw mudsucker. For example, while the wet-weight condition was high for Pond A8, those individuals also had high moisture content that suggests these fish were experiencing some stressor and retaining body water to compensate. Pond A8 is located at the upper end of Alviso Slough and experiences larger salinity fluctuations than other ponds and could explain the higher moisture contents. While the longjaw mudsucker can tolerate salinities from freshwater to three times the concentration of seawater, they tend to occur in salinities between 16-22 psu (Moyle 2002). Pond A8 is often below 10 psu and fresh at times during winter, suggesting osmotic stress may be important in A8. The hepatosomatic index was also low for fish collected in A8, which could suggest that fish are utilizing energy storage in the liver to compensate for an environmental stressor such as contaminants, but additional work would be needed to confirm the cause of lower health metrics for these fish. Similarly, fish in Alviso Slough inhabiting the remnant pickleweed marsh outside pond A6 had poor condition metrics; however, salinity is consistently higher at this site and typically in the preferred range for longjaw mudsuckers, so the poor condition of fish at this site is not likely due to osmotic stress. The abundance of longjaw mudsucker at this site was much higher than Pond A8, and the reduced condition of these fish may be due to the high densities of fish inhabiting the creeks and the competition for limiting resources. Alternatively, this site also had a higher prevalence of a microsporidian parasite that was first observed in tidewater goby and has been shown to cause severe health issues for host fish that often results in mortality (McGourty et al 2007). The microsporidian, *Kabatana* sp., has been observed in longjaw mudsucker from Walker Creek and Toms' Point marsh, both in Tomales Bay, and at China Camp State Park in San Pablo Bay and Stege Marsh in central San Francisco Bay; however, the prevalence in Alviso Slough was much lower than that seen in Tomales Bay marshes (Hobbs unpublished data). The infection status is only observable in the field once the fish has become severely infected, with large nodules of the parasite visible under the epidermis of the fish. The prevalence may be much greater than we observed and could explain the reduced condition of fish in Alviso Slough.

Skeletal deformities can often depict nutritional and contaminant stress. We found very few deformities overall in this study and found no evidence of the common deformity, scoliosis, which is often associated with poor feeding conditions. We did observe a few individuals with deformed maxilliae, which may be associated with contaminant stress. In Tomales Bay, the prevalence of maxillae deformities was high at sites along Walker Creek, which receives metallic mercury from an abandoned cinnabar mine. Similarly, Alviso Slough receives metallic mercury from cinnabar mines; however, we observed only three individuals in Alviso Slough with maxilla deformities and thus mercury contamination may not be as severe in Alviso Slough as previously observed in Tomales Bay.

Our individual health metrics from the fall sampling (% moisture, %lipid, otolith growth) were not statistically different between sites, due to the high within site variation among individuals and the small sample sizes used for the analyses. However, the patterns we observed likely reflect meaningful trends. While condition factor for fish collected during the fall subsampling for health metrics was not statistically different, the large sample set of condition factors measured during the monthly surveys did provide for a more robust analysis of condition differences among restoration ponds and seasons, revealing that condition did vary seasonally, with lower condition during the spring. Low spring condition factors likely reflect the post-spawn condition of the fish; however, we did not observe ripe females during our monthly surveys. Condition factors did not differ among the reference sites for the breached fully-tidal ponds (A6, A21); however, we did observe higher condition for fish collected inside muted tidal ponds compared to reference sites, specifically at SF2 and A8 , where the tidal stage is modified to keep the pond inundated for shorebird use. This effectively keeps the tide stage high and allows longjaw mudsuckers to forage for longer periods of time relative to habitats that are dry at low tide.

Abundance and survival estimates from the mark-recapture study did not appear to provide useful information regarding the population status of longjaw mudsucker in restoration ponds, as most pond sites had insufficient numbers of individuals tagged and recapture to calculate either metric. We did recapture sufficient number of individuals at several reference sites, outside the restoration ponds, and inside one restoration pond (A21), and were able to calculate annual abundance and survival estimates. Abundance patterns were similar to the catch per unit effort, except for the reference site outside A21, where the abundance estimate from mark-recapture was much lower than other sites, although catch per unit effort was relatively high at this site. This could be explained by the length of the creeks. The reference site at A21 has much shorter creek lengths (~5 m) as compared to the other reference sites and inside A21 (~40 m). Since we space the minnow traps out at 5 m distances, the total number of traps and thus effort at the site outside A21 is lower and represents less overall creek habitat. The catch per unit effort represent the relative density of fish for a length of creek habitat, thus the catch per unit effort is similar among the reference sites, when scaled to length of creek habitat, while the abundance estimate from the mark-recapture study are independent of habitat amount. These observations suggest creek habitats may have a limit to the number of longjaw mudsuckers they can support. At three sites with relatively similar lengths (50-75-m) we observed similar abundances (800-900) fish for four replicate creeks or approximately 200 fish per creek. If longjaw mudsucker are habitat limited and in most cases creeks are near capacity, the most appropriate and cost effective means to assess population status may be the use of presence/absence surveys with minnow traps at many creek habitats within a study area, rather than the more intensive catch-per-unit-effort approach with mark-recapture estimation. Moreover, given the seasonal patterns of fish activity and juvenile recruitment, targeted samplings in the late summer fall months only, may provide the best means to assess the status of longjaw mudsucker in restoration salt pond habitats.

The use of baited minnow traps to capture longjaw mudsucker, while the most reliable means to collect these fish, does pose logistical problems for monitoring the catch per unit effort year round and for conducting mark recapture studies. First, the sampling method is passive, requiring the fish to select a trap to enter primarily based on scent attraction to the bait. This results in an estimate of relative abundance that is dependent on the hunger level or at least the attraction to bait. In the winter months, the catch per unit effort declined dramatically and was more likely the result of decreased activity of the fish when water temperatures were cold, rather than a true decrease in abundance. This is apparent when conducting mark-recapture studies where each individual is given a unique tag and followed through a season within a creek habitat. Longjaw mudsuckers are known to not move long distances and usually do not leave their adult creek habitats. We observed in several instances individuals trapped multiple times at a single trap location within a creek during the summer and fall that were then not observed during the winter months but were subsequently recaptured in the spring the following year at the exact same trap location. Either these fish vacated these habitats in winter, which we do not think is the case, or they do not choose to enter the traps as readily when water temperature in the winter is low. Moreover, the capture probabilities from the mark-recapture study clearly showed low capture probabilities during the winter months, suggesting conducting minnow-trap-based surveys during winter months may not be appropriate for monitoring the relative abundance of this fish. The second problem with using baited minnow traps is that individuals learn quickly that food is available in the traps without consequence of predation and thus become “trap happy." We caught many of our uniquely marked individuals up to 7 consecutive monthly, while a majority of marked individuals were only observed once, or not at the same frequency. These differences in catch suggest that we had trap-happy fish. This can create bias in mark-recapture abundance and survival estimates as the capture-recapture probabilities are not equal among all individuals, which is an important assumption of most mark recapture models. Therefore abundance and survival rates in this study are likely biased by violating these assumptions

We conducted several intensive surveys at Bair Island and Eden Landing restoration ponds and reference sites using 60-80 minnow traps during 2010 and 2011 and observed very few longjaw mudsuckers. Both sites have large expanses of pickleweed marsh, with what we would consider appropriate habitat for this species; however, we found very few mudsuckers or other fish species. We did observe large numbers of the native mud crab *Hemigrapsus oregonensis,* which often averaged > 20 individuals per trap at both Eden and Bair. When high numbers of mud crabs were observed in the remnant marsh at SF2, we observed many dead, mostly consumed mudsuckers and other fish species, followed by a decrease in CPUE on the following survey. It is not clear whether mud crabs could actively prey upon the longjaw mudsucker, or if when trapped in high densities the crabs can cause significant mortality and scavenge the carcasses. The large numbers of crabs at these locations seem to be excessively high for the small creek habitats and may inhibit the longjaw mudsucker from establishing populations. Since the mud crab is a filter-feeder that can also scavenge detrital materials including dead organisms, the ponds may provide high abundances of prey for the crabs. Moreover, the pond habitats may support the retention of their pelagic larvae in the area and provide large numbers of recruits to adjacent remnant marsh. Further research would be required to discern causative mechanisms for the low numbers of longjaw mudsuckers at Eden Landing and Bair Island.

Conclusions:

We have developed a comprehensive and flexible monitoring regime for fish communities associated with salt-pond restoration (see appendix A). Using large seine nets that are deployed via small craft, set nets (i.e., gillnets and trammel nets), minnow traps, and otter trawls, we have documented the fish community that resides within the restoration areas and the adjacent sloughs in the Alviso Marsh Complex, the Bair Island Marsh Complex, and Ravenswood.

Of the 41 species of fish captured, only one (longfin smelt) is a listed species while several others are of commercial and conservation importance. The most numerous fish in the restored salt ponds are the physiologically tolerant threespine stickleback and Pacific staghorn sculpin, as well as the pelagic northern anchovy. Though the fish communities of the different restoration areas differed substantially between the studied complexes, the high CPUE within restored ponds was notable.

Restored and muted tidal salt ponds are harsh environments in summer and fall, when water temperatures reach extreme highs during the day and dissolved oxygen levels reach extreme lows at night. As a result, the species assemblages of these restored ponds are depauperate during these months, and only fish species tolerant of extreme physiological stress (i.e., Pacific staghorn sculpin, longjaw mudsucker, threespine stickleback) or able to move in and out of restoration areas on a daily basis (e.g. northern anchovy, leopard shark) commonly occur. In spite of the physiological stresses, the CPUE within the restored ponds (and occasionally in muted ponds) is extraordinarily high during these periods.

Several of the restored ponds and the immediately adjacent sloughs have higher densities of juvenile fishes in them than the surrounding area. Without further study investigating these juveniles' growth, survival, and recruitment into the adult population, it is premature to classify the restored ponds as nurseries. But there is no question that juvenile fish from several important species are using these habitats more than they are using adjacent ones, in spite of sub-optimal conditions within these areas. It is extremely likely that these fish are remaining in these physiologically stressful environments because prey densities are higher.

Both the abundance of juvenile fish within these habitats in spring and the abundance of tolerant adult fish in the summer indicate that these restored habitats are attracting and holding fish from several species. Otter trawl bycatch and limited invertebrate sampling indicate that several invertebrate taxa commonly preyed upon by fish elsewhere (e.g., mysid shrimp and amphipods) are considerably more abundant within the restored ponds than in the adjacent sloughs and mudflats. Presumably, many of these fish are attracted to these areas to forage, and if possible, will remain in and around these restored ponds for quite some time.

Monitoring the population and individual health of the sentinel fish species, the longjaw mudsucker, has revealed that recently restoration ponds have yet to provide permanent habitat for the longjaw mudsucker, an obligate intertidal pickleweed marsh specialist. However, pond A21 of the Island Pond complex, which was first breached in 2006, does support large numbers in the sections of the pond that have developed pickleweed marsh habitat. Recently restoration ponds, A6, A8, and SF2 did receive large numbers of juveniles during the summer months when new recruits were seeking out intertidal creek habitats; however, very few individuals appeared to overwinter inside restoration ponds and recruit to the adult population the following year. If these ponds begin to develop marsh habitats, juvenile recruits should be able to take advantage of newly formed habitats and establish new populations.

Individual condition factors suggest that conditions for feeding and growth inside restoration ponds were satisfactory, however we did observe some evidence for environmental stress effects. Health metrics associated with nutritional state and growth were not statistically significant, primarily due to low sample sizes. We observed very few visually diseased or deformed individuals in restoration ponds or reference sites; however we did find a microsporidian parasite that is known to have deleterious effects on its' host. Overall, the condition and health of the sentinel species in restoration ponds and reference sites were in good health condition, and very little effects of environmental stressors were found. Additional research will be required to further investigate health indicators in restoration ponds, including increasing samples sizes where possible.

Population abundance estimation and catch per unit effort data collected at the restoration pond and reference sites suggest that the population abundance of longjaw mudsucker may be limited by the amount of available creek habitat. Catch per unit effort data appeared to be a good indicator of fish density, and that creeks of different size supported different numbers of individuals that scaled with creek length. Longjaw mudsucker are known to reside in high intertidal burrows within creeks, and depend solely on picklweed marsh creeks to thrive. Given we observed similar density of fish among the many creeks we sampled, effective monitoring of this species may take a different approach than the one we used in this study. The presence/absence of the longjaw mudsucker in creeks of restoration ponds and reference sites may be a more efficient means of assessing the status of the species. Quantifying the presence/absence status would require much less effort for a single creek and would provide for more sampling to occur spatially. In addition, we had very low catch and capture probability of tagged individuals in winter months and high catch in summer to fall months suggesting efforts could be focus more within the summer and fall.

Several sites produced very few longjaw mudsuckers, including the restoration pond on Outer Bair Island and among the remnant picklweed marshes at Bair Island, and the ponds at Eden Landing (E9, E8, and E8X), including references creeks in the Whales Tail Marsh. The sites in the remnant marsh at Bair Island and Eden Landing had vast expanses of pickleweed marsh with creek habitats that should support large number of longjaw mudsuckers, however we found very few fish. It isn't clear why we don't find many longjaw mudsuckers in these reference sites but this suggests establishing populations in recently restoration ponds at Bair Island and Eden Landing would take much longer than expected. Further research may be needed at these sites to elucidate the cause of absence or extremely low numbers of longjaw mudsuckers

Regarding the lost data from January-April 2012 for minnow trapping efforts

Note that while we do not report minnow trap data for January-April 2012, we did sample using our standard monthly survey protocol, but datasheets were stolen from this time period and no data were reported. Catch of longjaw mudsucker was low during this period overall (Hobbs pers. obs.), and likely had little effect on our ability to discern patterns regarding comparisons between restoration ponds and reference sites. We did mark 221 individuals during this time period at four sites and were able to determine where each tag was used during the interval and were able to use the recapture of these individuals in abundance and survival estimates. Because we found little difference in the survival estimates among sites, we feel the data loss would have had very little effect on these estimates. The abundance estimates were also likely not significantly affected by the data loss as error on the estimates was small and patterns were robust. The data loss occurred during the winter period when catch is low and recapture probabilities are at a minimum. In addition to the minnow trapping data loss, we also lost data for beach seining at pond A8 and A6, however we collected very few fish during those surveys. We had also started implementing the use of a smaller otter trawl deployed from our 14 foot Jon boat, to be used inside A6, where it is difficult to sample with our larger boat and trawl. We had conducted two trawls inside A6 in March, which we lost data for. From memory, we caught several hundred newly recruited staghorn sculpin, however we saw large numbers of staghorn in the large boat otter trawl during the same month in Alviso Slough, thus the information loss was likely minimal.

Recommendations for future studies

Fish Community Study

The goals of the fish community study were to determine a flexible and comprehensive monitoring program to assess the impacts of salt pond restoration on fish communities and to document the fish communities within restored salt ponds and the adjacent habitats. We were successful in developing a monitoring technique using a combination of otter trawling, seining and gill/trammel netting (see appendix 1). The appropriate amount of effort required to document the communities within the restoration areas was also determined for all locations except Eden Landing. We make the following recommendations to for the continuation of the community study:

Continue on-going studies with some modifications:

1. Continue monthly sampling using seines, trammel/gill set nets and otter trawls within the Alviso Marsh Complex and Bair Island Marsh Complex. Because fish communities within the restoration marshes are extremely dynamic, monthly sampling is necessary to determine the communities present throughout the year, and the extent of similarity between restored and unrestored habitats. Given the potential presence of several listed species within these habitats (steelhead, green sturgeon, spring-run Chinook salmon, longfin smelt), sampling as frequently as possible maximizes our likelihood of detection.

2. We recommend bi-monthly sampling at Ravenswood and Eden Landing for two different reasons:

Ravenswood is tidally muted, and the water is not completely exchanged within the Bay. Our preliminary sampling data for this area indicates that the species assemblage in this pond is not as dynamic as in fully tidal systems, and monthly sampling is not needed to accurately assess the communities present in this pond.
The Eden Landing restoration area has an extremely high marsh plain, and rarely has enough water for fish species to move into the restoration area, and it has not accrued sufficient pickleweed to facilitate mudsucker populations. This results in very few fish utilizing the restored ponds, besides leopard sharks in the scour hole at the E9 breach. Sloughs surrounding the restoration ponds have been sampled with the 14ft Jon boat and small otter trawl with abundance of fish collected however access is prohibitive of consistent sampling until a secure launch is created. We therefore recommend sampling Eden Landing bi-monthly.

New Study Concepts

1. Leopard shark and other large predator abundance and diet surveys:
   We recommend continuing a pilot project we initiated in August 2011 examining leopard shark, striped bass and bat ray stomach contents in restored marshes and adjacent sloughs. These three predators are the apex of the non-mammalian aquatic food-web in the restoration marshes. Diet analysis of these predators allows us to determine the quantity and quality of food that is provided to large predatory fishes in the restoration marsh compared to unrestored sloughs.

2. Additional fully tidal sites:
   We recommend including new fully tidal sites (Middle Bair Island and Pond A17) in the sampling regime to allow for the further assessment of recently breached habitats. The analysis of fish communities colonizing habitats immediately following restoration is of immediate concern for managers in SFE, given the possibilities of levy failure elsewhere in the Bay/Delta. The ongoing restoration of salt ponds provides an excellent venue to assess the immediate response of aquatic communities to restoration. Because we have two years of data collected adjacent these restoration locations, we are ideally situated to monitor the early stages of restoration. Because of our sampling methods (entirely boat-based) the addition of two more locations is extremely feasible and can be accomplished with minimal additional effort.

3. Additional muted or managed ponds:
   We recommend the addition of at least one longterm managed pond site per complex (e.g. A5/7, E12-13) as well as conducting intermittent sampling at other managed ponds during monthly surveys. Our research focuses heavily on full tidal and muted ponds, however we currently don't sample ponds that are managed for water levels for ducks and shorebirds. Salinities in managed ponds can be very high at times (>80ppt) which precludes many fish, but some ponds can be much lower, and be similar to adjacent sloughs. Monitoring the fish communities of these ponds across different salinity

regimes would provide us a better understanding how these managed systems effects fish populations in relation to the muted and fully tidal systems. In addition we would like to add the new muted pond A16 given its similar configuration to SF-2, which we will continue to monitor bi-monthly.

4. We also intend on further analysis of the first two years' data using time series regression of individual fish species' population growth rates , cluster analysis to determine the geographic similarities in observed species assemblages, and ordination (CCA, DCA, NMDS) to identify the principle abiotic factors responsible for observed assemblage shifts.

Sentinel Species Monitoring

The goal of this study was to gather baseline information on the individual and population health of a sentinel species for salt pond restoration. The longjaw mudsucker is the only fish species that depends on pickleweed marsh, and has a small enough home-range to reveal effects of individual salt pond restoration actions. However, we found too few individuals in many of the restoration ponds to effectively utilize the species health status as an indicator of the restoration actions. At these sites, pickleweed marsh had not developed significantly and likely explains the low numbers of fish. Furthermore, the small population sizes made it difficult to collect enough individuals to quantify many of the health metrics. Given the limitations of using the longjaw mudsucker as a sentinel species for fish health, we make recommendations to improve study designs to continue the use of this species as an indicator. Our recommendations also take into consideration new decisions regarding the use of baited minnow traps for collecting longjaw mudsuckers in pickleweed marsh, as the use of this gear type can have adverse impacts to the endangered salt-marsh harvest mouse, and sampling some marsh sites may be precluded by the endangered clapper rail.

1. Annual sampling – Our monthly sampling efforts clearly revealed a seasonal pattern to the relative abundance, such that effort should be focused in the summer months. Recruitment of juveniles to the populations appeared to be complete by August, therefore to represent annual abundance index, we recommend focusing sampling efforts to a single survey during the months of August or September during the spring tide series.

2. Minnow trapping - Very few individuals were collected in beach seine or otter trawl gears so we recommend using minnow traps to collect longjaw mudsucker. To minimize the impact to harvest mice we recommend only trapping during the high tide, and removing traps before the next high tide, to avoid drowning trapped mice. (*Although incidentally trapping an endangered fish would still constitute take under the Federal Endangered Species Act)*. This would preclude sampling multiple sites on the same tide because it takes too much time to reliably collect traps before the next tide. Therefore

an annual sampling at many sites may be possible during the 3-5 days available for sampling during the spring high tide series. Sampling in the months of August or September would also preclude issue with Clapper Rail as currently sampling is allowed after during this period.

3. Health monitoring – First, we recommend increasing the sample size for individual health metrics during the August-September sampling period. In this study we attempted to minimize the numbers of fish sacrificed for health metrics because we were using the same sites for mark-recapture studies. Several metrics should be included in the health portfolio, including biomarkers of contaminant exposure, particularly for mercury exposure in the Alviso Marsh as mercury is a known issue in this area.

4. Sampling sites- During the study we only found significant numbers of longjaw mudsuckers inside pond A21. Pond A21 has the most pickleweed marsh of all the restoration ponds and this species is dependent on pickleweed marsh habitat. It will likely take many years for other ponds to develop pickleweed marsh habitat, therefore, monitoring may take place at long time intervals to allow for the recovery of pickleweed marsh. Given the species life-span (2-3) years in San Francisco Bay, we recommend sampling at a 3 year time interval.

5. Focusing studies at larger spatial scales- Pond restoration will not only create new marsh habitats, but will benefit adjacent habitats by increasing primary and secondary production. We have sites along Alviso Slough and Coyote Creek in the fringing marsh outside restoration ponds A6 and A21 that could be monitored for sentinel species for groups of restoration ponds within a slough. For example the site outside A6 could be monitored for restoration effects of both pond A8 and A6. However this study design would require a slough site that does not have restoration ponds. The Newark Slough Marsh would be a good candidate as a "control" site.

Other sentinel species

There are other species that could be used as sentinel species of health, although residence time within a particular pond would not be similar to the longjaw mudsucker. The staghorn sculpin is a native estuarine species that occurs in high abundance in many of the restoration ponds. Otter trawl data suggests that staghorn may select pond restoration sites Coyote Creek (A21 & A19). However, this species can be found in slough habitats and the bay, and probably only utilizes ponds during high tides and may move around too much to be an indicator of a single pond restoration. The three-spine stickleback is small native estuarine fish that occurs in shallow water habitats, and has been found in large numbers inside restoration ponds, but could be found in slough and shallow bay habitat as well. The top-smelt is another small native estuarine fish that can be found frequently inside restoration ponds. However, like the staghorn sculpin, the residence time within the restoration ponds is unknown and they are often found outside the ponds along the sloughs, thus making it difficult to associate the health of the fish to any particular restoration.

Using multiple sentinels

Another approach may be to utilize many species for indicators of health. Combining multiple species within a small spatial scale could provide another means to monitor the health of fish in association with restoration ponds. Using species with different life history or habitat requirements could provide a powerful approach for assessing the overall restoration benefits to fish health. Combining species that utilize different micro-habitats created by restoration could give you a more inclusive perspective on how restoration may benefit a community of species. Health metrics could be chosen to best reflect each species use of the restoration ponds. Given the short residence time of most fish species within the restoration sites, quick responding health indicators could be used. For example, stomach fullness could be used to determine how well a fish is feeding over a few hours, and daily otolith increment widths could be used as a proxy for growth over a few days. Enzyme biomarkers of contaminant stress can reflect very short term exposure. Combining short term metrics with some long term metrics such as condition factor can provide for a power tool to examine fish health in the restoration ponds.

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Appendix A:

Otter Trawling Efficiency

Species accumulation curves were plotted for Coyote Creek, directly adjacent to the Island Ponds and within the Island Ponds themselves (Figure a1 and a3), in order to determine the appropriate sampling effort in a representative slough habitat and a representative restored habitat. Species such as longjaw mudsuckers, which rarely leave intertidal creeklets, remaining even at low tide, and Mississippi silverside (*Medina audens*), which inhabits inshore shallow habitat nearly exclusively, were not represented in the communities sampled via otter trawl. Neither were large, fast-swimming species such as white sturgeon.

Four months' trawl catches from Coyote Creek were compared (Figure a1). By the time 30 minutes of trawling was conducted, no additional species were captured, regardless of the overall diversity of the assemblage within Coyote Creek. Based on the smooth, asymptotic shape of the species accumulation curve, we inferred that the sampled habitat was relatively homogenous and that few species emigrated/immigrated from the sampling area while we were conducting surveys (Magurran 2004).

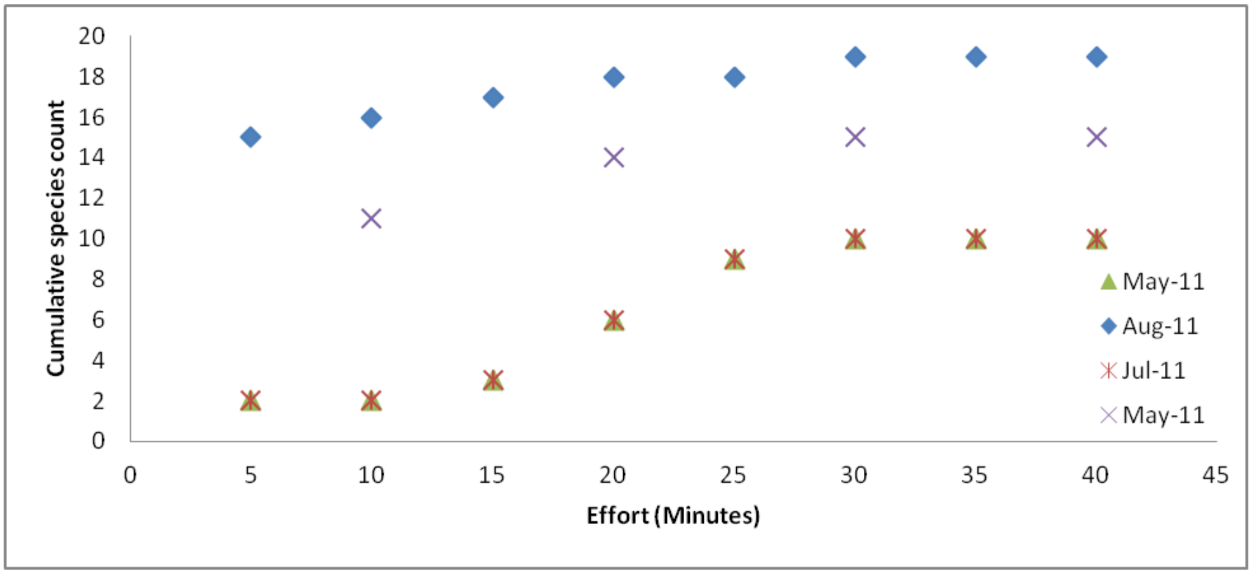

Figure a1. Species accumulation curve within Coyote Creek for four representative months (Months were chosen to maximize differences in diversity and abiotic conditions). May is exactly the same as Jul.

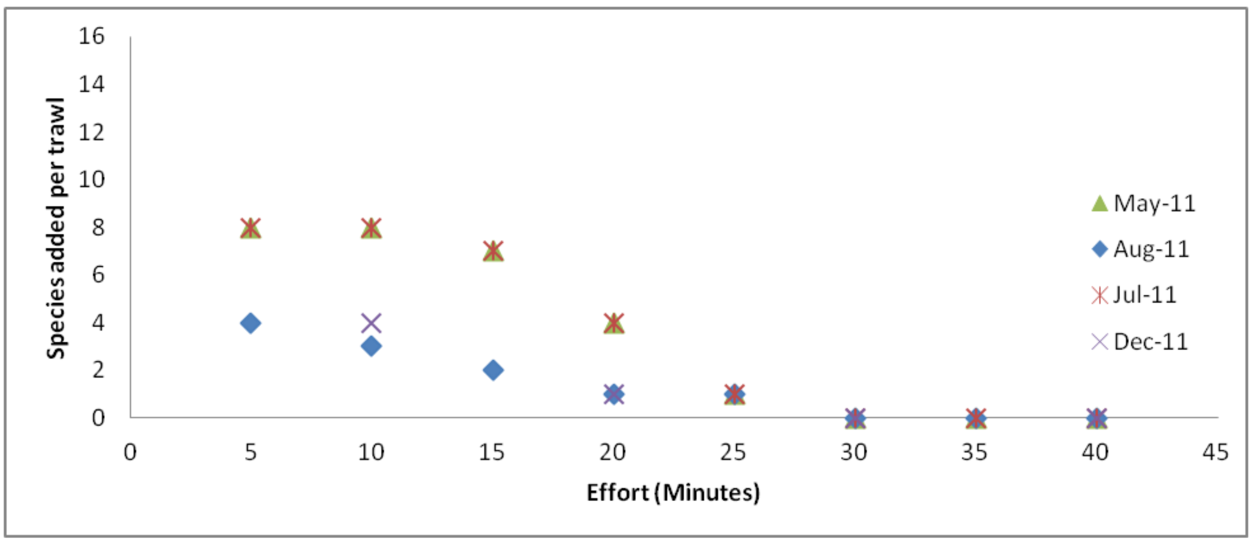

Figure a2. Additional species documented per trawl within Coyote Creek for four representative months.

Trawl catches from within the Island Ponds were also compared from the same months. The Island Ponds species accumulation curves showed considerably more variation than did the adjacent slough, which indicates that the habitat is more heterogeneous or more species immigrated into the ponds while sampling was taking place. Empirical observation shows that the Island Ponds are a more heterogeneous environment: they are bordered by both mudflat and newly vegetated marsh plain, have depths ranging from decimeters to meters, and have extremely variable water quality parameters due to tidal trapping and mixing (Maclean and Stacey 2011). This heterogeneity undoubtedly explains some of the variation in the accumulation curves, though the movement of species into these habitats cannot be discounted. In spite of this variation, it appears that 35 minutes of trawling effort document all but the rarest species. In two months (August 2011 and December 2011), 10 additional minutes of effort (two trawls) was expended and no additional species were detected.

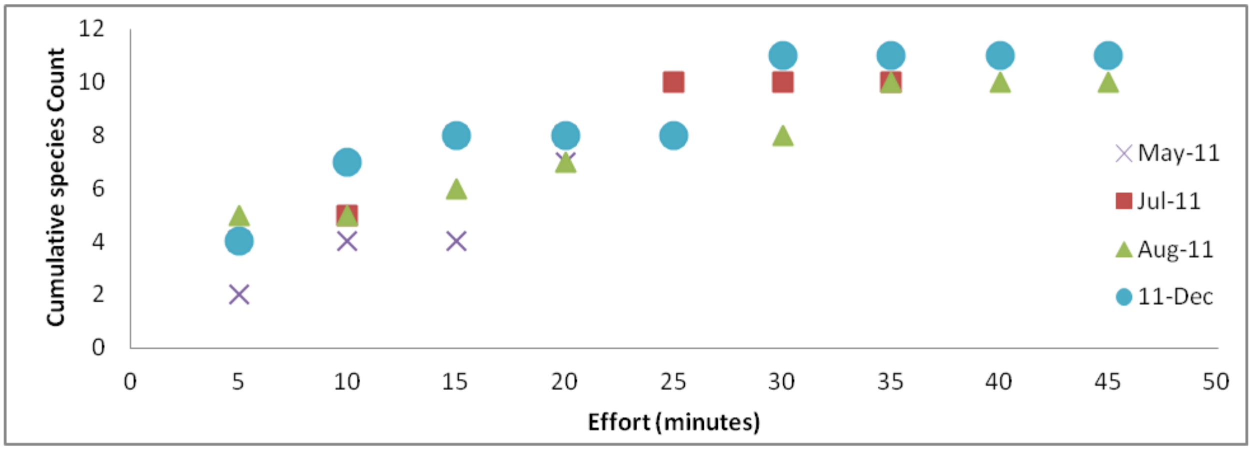

Figure a3. Species accumulation curve for the Island Ponds for four representative months .

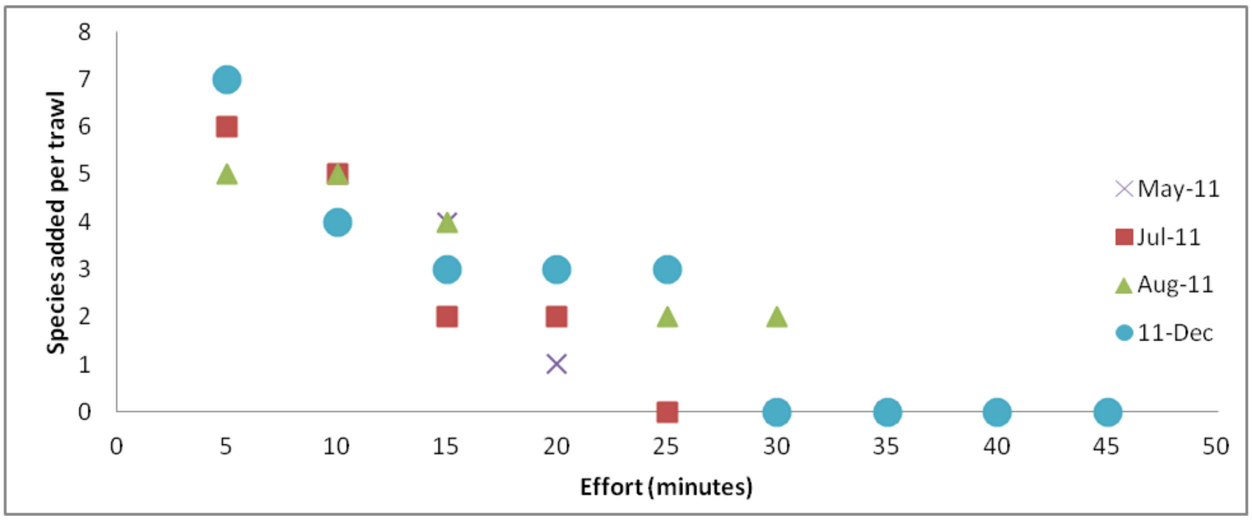

Figure a4. Additional species documented per trawl within the Island Ponds for four representative months.

The ability to use such a simple method to determine appropriate effort is only possible because estuaries are typically a low-diversity, high-abundance environment with a depauperate native community, especially on the tectonically active Pacific Coast.

Because long trawls dramatically increase fish mortalities the appropriate amount of effort (in minutes) was divided into multiple shorter trawls (5 or 10 minutes). Typically five minute trawls are used in smaller sloughs and restored ponds and 10 minute trawls are used in larger slough habitats.

Limitations of otter trawling:

Otter trawls were used to sample intertidal and sub-tidal sloughs (depths >0.75m); however, because otter trawls run along the bottom, sample a fixed volume of water, and are pulled a fixed speed, intuition states that the effectiveness will be limited. There are three questions regarding otter trawl effectiveness that we have addressed: (1) Are there marsh resident species, which rarely/never enter the sloughs sampled with the otter trawl, but inhabit the marsh habitat? (2) Are there surface-oriented/peripheral habitat specialists that never enter the water column? (3) Are some species capable of evading the otter trawl?

Are there marsh resident species?

The intertidal marsh was sampled using minnow traps placed in creeklets adjacent to otter trawling locations. The only fish species in the sample area that was captured in the creeklets but not in the sloughs was the longjaw mudsucker. Longjaw mudsuckers are residents of intertidal marsh and rarely leave high-intertidal habitat (Williams and Zedler 2000). Longjaw mudsucker is a native gobiid that is being used as a sentinel species for salt-pond habitats and are sampled using minnow traps placed in the intertidal creeklets (see Sentinel species report). Mudsuckers comprise over 2/3 of the minnow trap catch and constitute less than 1% of the otter trawl catch. Other fish species (e.g., staghorn sculpin) captured in minnow traps were also captured in sloughs at low tide.

Are there surface-oriented/peripheral-habitat specialists?

30 years of Suisun Marsh fish sampling has demonstrated the limitations of otter trawl sampling when it comes to the near-shore assemblages: the communities observed via otter trawl differ substantially from those in beach seine hauls (Matern et al. 2002). Mississippi silversides are the most notable species that is under-sampled by otter trawl in Suisun Marsh, although the littoral assemblage of Suisun is different even without including the silversides (O'Rear and Moyle 2011). In the South Bay, there are three silverside species that are known to be common and yet are uncommon in trawl catches. Seines are the preferred method for sampling these near-shore fishes; however, the poorly consolidated sediment of the South Bay makes traditional beach seining dangerous (pers. obs, Photo 10). After much experimentation, we have determined that a large seine (30 m) deployed from a boat and retrieved by two people standing clear of the mud is the best and most effective way to sample these habitats. Seine catches were typically less speciose than otter trawls, but they effectively sample all three of the silverside species, juvenile fish common in otter trawl catches, and other near-shore species that are relatively uncommon in trawls such as rainwater killifish (*Lucania parva;* Appendix Fish) Because seine surveys were only initiated in the fall of 2011, they will not be discussed in detail in this report, other than to note that we have begun implementing them and have circumvented the problems posed by the poorly consolidated South Bay sediments.


Photo 10: Hazards of walking on mudflats. Photo: Georgia Ramos.

Do some species evade the trawl?

Because trawls are towed at a speed of about 2.5 knots, fast-swimming fish species will inevitably swim out of the trawls path and evade capture. Gill- and trammel nets (set nets) have been used to determine what species are capable of evading the trawl, with surveys beginning in May 2011. 14 species were captured by gillnet over the year that they have been employed, and all of them were also captured, at some point, in trawl surveys. However, four species captured in set nets were only captured as juveniles in trawl surveys (leopard shark, American shad, jacksmelt, and striped bass), and one additional species (white sturgeon) was much more common in set nets than in the trawl. Set nets are useful for determining which species are present within the marsh, but low catches make them less suitable for documenting species assemblages even in a depauperate community.

Photo 11. White sturgeon can usually evade otter trawl surveys and are thus rarely captured.

Species	Adults in trawl?	Adults in set nets?	Juv. In trawl?
American shad	**No**	**Yes**	**Yes**
barred surfperch	Yes	Yes	Yes
CA bat ray	Yes	Yes	Yes
diamond turbot	Yes	Yes	Yes
English sole	Yes	Yes	Yes
jacksmelt	**No**	**Yes**	**Yes**
leopard shark	**No**	**Yes**	**Yes**

Northern anchovy	Yes	Yes	Yes
Pacific staghorn sculpin	Yes	Yes	Yes
shiner surfperch	Yes	Yes	Yes
starry flounder	Yes	Yes	Yes
striped bass	**Occasional**	**Yes**	**Yes**
topsmelt	Yes	Yes	Yes
white sturgeon	**Rare**	**Yes**	**n/a**
yellowfin goby	Yes	Yes	Yes

Table 1. Species captured in set nets and their presence in otter trawl surveys. Discrepancies between the two are in bold.

<u>Frequency of sampling</u>

Ideally, each sampling trip will perfectly document the species community that is present at that time, as well as document the seasonal variation that occurs. Aquatic communities are unfortunately extremely dynamic and are sensitive to a suite of abiotic and biotic factors that vary at many spatial and temporal scales. Initially we began sampling the marsh bimonthly; however, sampled communities were extremely dissimilar between these trips (Figure a5). Because the inter-month differences between sampled communities exceeded the intra-complex differences (i.e., the community sampled in August 2010 and October 2010 was more different than any of the areas sampled on either trip), any sort of consistency within the data set was deemed impossible. In addition, our ability to account for short-term stochastic events (e.g., storm systems that alter abiotic factors such as temperature and salinity and thus affect the fish community) was hindered. To compensate, we adopted a monthly sampling protocol in order to better document the effects of restoration on the annual assemblage in the marsh and to have some semblance of insurance against short-term perturbations. Monthly sampling increased the similarity between sampling trips (Figure 37) in both presence/absence and relative-abundance metrics.

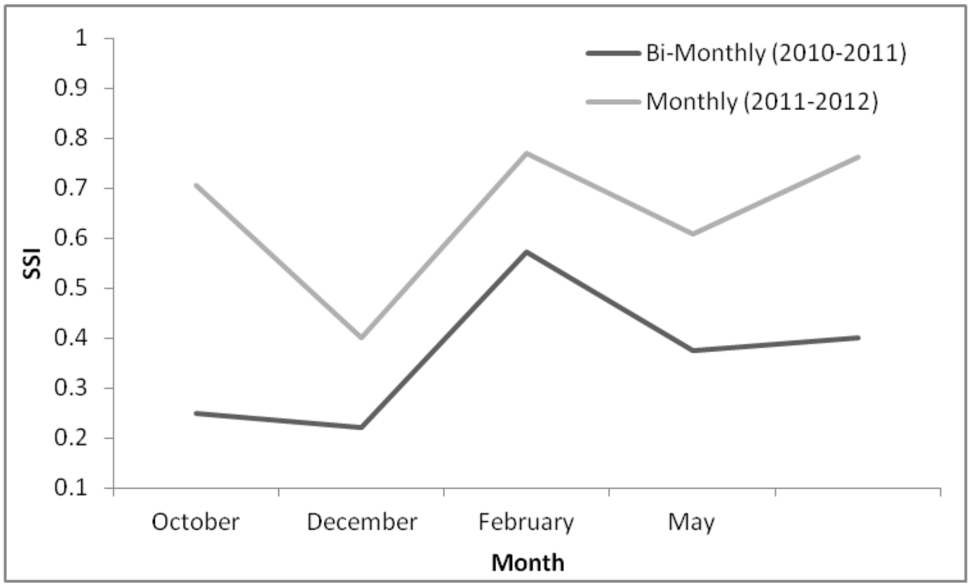

Figure a5-A. Sørensen pair-wise similarity index between consecutive sampling expeditions to the Alviso Marsh Complex. The Sørensen index operates using only the presence/absence of species.

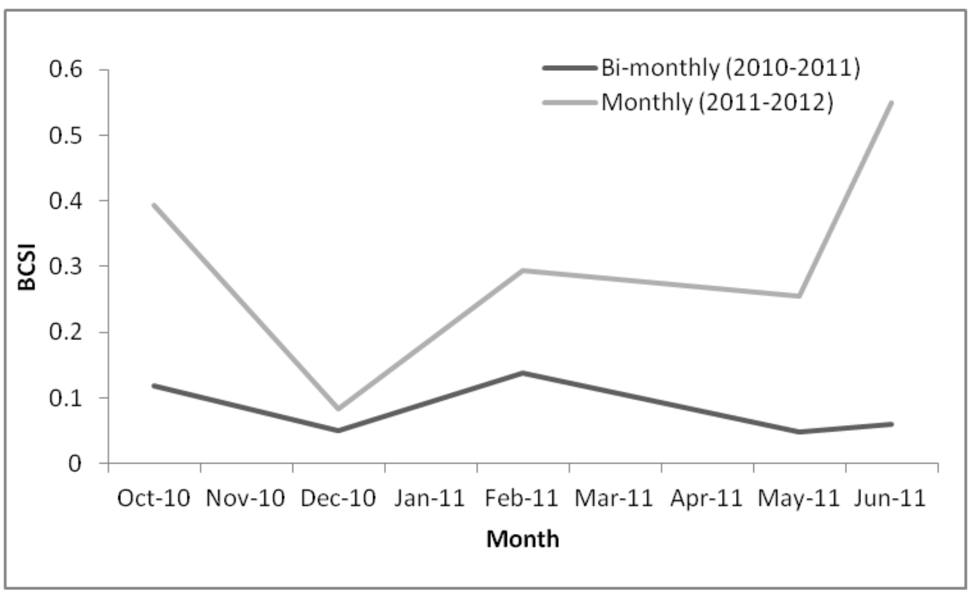

Figure a5- B. Bray-Curtis pair-wise similarity index between consecutive sampling expeditions to the Alviso Marsh Complex. The Bray-Curtis index operates using both presence/absence and the relative abundance of species.

Appendix B:

Total fish captured via otter trawl for the duration of the study at the Alviso Marsh Complex and Bair Island and associated restored ponds.

Alviso Marsh	Jul-10	Aug-10	Oct-10	Dec-10	Feb-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Mar-12	Apr-12	May-12	Jun-12	total
three-spine stickleback	236	223	828	392	261	19	3	604	1370	2484	912	200	496	99	119	10	8	76	8340
Pacific staghorn sculpin	74	59	68	43	27	151	527	89	55	284	617	407	589	104	1038	1564	292	343	6331
Pacific herring				23	11	733	28	2	1		1	1	8	1	771	296	1	1	1878
English sole					1	8							2	65	1369	270	2	1	1718
Northern anchovy	130	110	17	8		15	8	178	133	151	34			1	24	223	78	206	1316
arrow goby	39	60	6	2		9	74	374	81	6	1		5		70	9	92	122	950
yellowfin goby	25	13	8	5	8	9	12	73	23	29	40	40	68	53	28	18	23	220	695
topsmelt	2		29	294	2	2			4	2		1	26	11	1		1		375
Mississippi silverside				2					3	11	1	8	313		2				340
longfin smelt				61	7						2	4	99	15	17				205
starry flounder		1	10	1	2		2	8	3	4	20	11	23	16	23	12	9	48	193
American shad				8	4	2				3			85	26	10	5	1	3	147
jacksmelt								49	21	6	14		4						94
speckled sanddab				4	60	1	1							3	2	3			74
prickly sculpin	9	1			3	9	9	5	4	3	2	2	4	11	4	2	2	3	73
striped bass		1				4	1	2	1			1			1	32	20	8	71
shiner surfperch	2		1	1		16	2				1	3	6	2	11	12	1	1	59
bay pipefish		7				3	1	3	4	5	7	1	4	6	5	3	1	2	52
rainwater killifish	2	1	5	1	4	1		2	14		3		11					2	46
CA bat ray	4	4	1					1	3	18		1			1	1	1	3	38
threadfin shad				12	1								7	8	5				33
longjaw mudsucker		1			1			8	1	5	2		2				4		24
California halibut																9	6	7	22
Pacific lamprey					4									18					22
Sacramento sucker	1										2	1			1	1	3	4	13
bay goby																8	2	1	11
plainfin midshipman								2		2								1	5
leopard shark		1	2																3
shokahaze goby				1													2		3
shimofuri goby	1															1			2
barred surfperch													1						1
Chinook salmon																	1		1
diamond turbot						1													1
surf smelt															1				1
white sturgeon																1			1

COYOTE CREEK	Jul-10	Aug-10	Oct-10	Dec-10	Feb-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Mar-12	Apr-12	May-12	Jun-12	Total
Pacific staghorn sculpin	2	4	1	6		22	2	5	28	20	22	15	342	63	369	293	72	39	1305
English sole					1								2	51	971	79			1104
three-spine stickleback		2		6	1	2		74	280	28	2	9	157	30	7			2	600
Northern anchovy	6	2					4	23	35	25					9	193	3	30	330
Pacific herring				5	2	70	1		1				2		145	1		1	228
arrow goby	4	5		1			10	32	57	1	1				13		6	8	138
yellowfin goby		1				3	1	3	15	17	1	5	35	8	4	1	4	24	122
longfin smelt				17								1	67	5	7				97
American shad				2	4								48	13	3	1	1	1	73
speckled sanddab					39	1								2	1	1			44
starry flounder			1		1		1	3	1		1		9	2	6	6	2		33
striped bass						3		2	1			1				13	5		25
shiner surfperch						7							5	1	6	4			23
bay pipefish								3	3	1	2		3	3	3		1	2	21
California halibut																6	6	5	17
rainwater killifish						1		1	14										16
topsmelt				1	1				1	2			5						10
CA bat ray		1						1	2	5									9
jacksmelt									6	1	2								9
Unidentifiable						5											3		8
Mississippi silverside									1				6						7
prickly sculpin									3	1			2		1				7
threadfin shad													2		2				4
bay goby																	1	1	2
Pacific lamprey														2					2
Chinook salmon																	1		1
diamond turbot						1													1
longjaw mudsucker													1						1
shimofuri goby																1			1

ISLAND PONDS	Jul-10	Aug-10	Oct-10	Dec-10	Feb-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Mar-12	Apr-12	May-12	Jun-12	Total
three-spine stickleback	234	141	10	28	38		1	304	99	2268	745	18	132	19	65	4	5	22	4733
Pacific staghorn sculpin	8	25	20	1	16	49	31	35	14	172	337	234	50	19	186	513	103	223	3341
Pacific herring				11	6	361		1				1	4		370	259			1241
English sole														2	16	1			1123
Northern anchovy	96	67	8	1		6	1	88	77	89	24			1		9	11	97	905
arrow goby	24	7				1	47	131	16	1					30	7	78	48	528
yellowfin goby	8	10	3		6		6	48	6	3	9		3		12	4	10	179	429
longfin smelt				20	6						1	2	5	5	3				139
starry flounder		1	9	1				5	1	3	10	2	5	1	1	5	5	39	121
American shad				1									6	6	1	1			88
topsmelt	2		2	49	1				3				12	4					83
speckled sanddab				2	6														52
Unidentifiable						37													45
jacksmelt								6	15	2	7		4						43
shiner surfperch	2					6	2									2		1	36
striped bass						1										6	2	1	35
bay pipefish						1	1		1		2					3			29
rainwater killifish					1			1			1		1						20
California halibut																		1	18
prickly sculpin						6					2					1			16
threadfin shad				6	1								1	2	2				16
bay goby																6	1		9
CA bat ray																			9
Pacific lamprey					1									6					9
longjaw mudsucker		1						2			2						2		8
Mississippi silverside									1										8
leopard shark			1																1

Bair Island Marsh	Jul-10	Aug-10	Oct-10	Dec-10	Feb-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Nov-11	Dec-12	Jan-12	Mar-12	May-12	Jun-12	total
Pacific staghorn sculpin	7	2				51	9	11	66	1		6	24	120	638	115	1051
Pacific herring					4	209							1	395	21		657
Northern anchovy	78	140	9	30	37	9	30	49	56	3	1	21	28	16	25	52	584
shiner surfperch	17	9	7	1	3	12	14	17	29	3	2	65	30	4	101	98	412
bay goby							12		11			3	1		166	59	253
English sole				1		72	16						6	8	54		157
arrow goby	16	14	2	1			1	2	27	3		1	3	18	20	37	145
topsmelt	3	21	13	21	3	8						4		1	8	30	112
chameoleon goby						4	1		1	2		4	7	1	5	2	27
yellowfin goby	3			1		15			1				2				22
white croaker									4				1		11	2	18
dwarf perch													12			2	14
barred surfperch	1	2							1			1	1	3	2	2	13
leopard shark	3	2				2			1						1	2	11
brown smoothhound		5													3		8
CA bat ray	3	3													1	1	8
speckled sanddab			1	1		4									1	1	8
starry flounder	1	1							2					1			5
Mississippi silverside												4					4
plainfin midshipman		1				1	1	1									4
three-spine stickleback												1					3
jacksmelt															1	1	2
threadfin shad													2				2
bay pipefish													1				1
California tonguefish															1		1
diamond turbot														1			1
longfin smelt													1				1
shokahaze goby				1													1

MIDDLE BAIR	Jan-12	Mar-12	May-12	Jun-12	Total
Pacific staghorn sculpin	21	110	432	34	576
Pacific herring		156	1		157
shiner surfperch			3	67	70
arrow goby		4	11	17	32
Northern anchovy	17	4			4
English sole	2	2			2
diamond turbot		1			1
dwarf perch				1	1
barred surfperch					0
bay goby					0
CA bat ray					0
jacksmelt					0
leopard shark					0
threadfin shad	1				0
topsmelt					0
yellowfin goby	1				0

STEINBURGER	Jan-12	Mar-12	May-12	Jun-12	Total
Pacific herring		17	20		37
topsmelt			4	28	32
Pacific staghorn sculpin		4	10	14	28
Northern anchovy	4		6	15	21
arrow goby	2		5	12	17
shiner surfperch			4	5	9
barred surfperch	1			2	2
CA bat ray			1	1	2
English sole	3	2			2
jacksmelt			1	1	2
leopard shark				2	2
bay goby	1				0
diamond turbot					0
dwarf perch					0
threadfin shad					0
yellowfin goby					0

Appendix C

Total number of minutes otter trawled each month in each slough

	Jul-10	Aug-10	Oct-10	Dec-10	Feb-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Mar-12	Apr-12	May-12	Jun-12	Total
A6	0	0	0	5	0	0	0	10	0	0	0	0	10	10	5	0	0	0	40
ALVISO SLOUGH	15	15	15	15	15	25	20	20	20	20	20	20	20	20	15	15	15	10	315
ARTESIAN	0	0	10	10	10	10	0	0	0	0	0	0	0	0	0	0	0	0	40
COYOTE CREEK	10	10	20	20	20	35	20	40	85	45	35	30	40	40	40	40	40	40	610
ISLAND PONDS	15	15	30	25	35	30	10	35	50	35	35	35	35	35	35	35	35	35	560
LOWER COYOTE CREEK	20	10	10	20	10	30	0	40	20	40	20	30	10	20	20	20	20	20	360
MUD SLOUGH	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Upper Coyote Creek	0	0	5	5	10	20	0	5	5	10	15	20	20	10	20	25	20	20	210
EDEN LANDING	0	0	15	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	35
BAIR ISLAND	20	30	25	20	30	25	10	10	10	10	0	5	30	30	30	0	30	30	345
BAIR-DEEPWATR CHANNEL	10	20	10	10	10	20	20	20	20	10	0	10	20	10	20	0	20	20	250

Appendix D

Total number of fish captured via beach seine in 2012 (since seining was standardized)

Month/Species	ALVISO	RAVENSWOOD	EDEN
January			
No Catch	1		
rainwater killifish	1		
three-spine stickleback	1		2
topsmelt			25
March			
bay pipefish	1		
Mississippi silverside	12		
Pacific herring	37		
Pacific staghorn sculpin		9	
shiner surfperch		1	
topsmelt	1	7	
May			
bay pipefish	2		
diamond turbot		1	
English sole	7		
Mississippi silverside	27		
Northern anchovy	17		
Pacific staghorn sculpin	35	47	6
rainwater killifish	12		
shiner surfperch	1		
three-spine stickleback	18	10	10
topsmelt	64		20
yellowfin goby	6	3	3
June			
longjaw mudsucker	4		
Mississippi silverside	14		
Northern anchovy	10		
Pacific herring	1		
Pacific staghorn sculpin	19	14	
rainwater killifish	16		
shiner surfperch	1		
three-spine stickleback	28		
topsmelt	39	1	
yellowfin goby	27	48	

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Longfin smelt: spatial dynamics and ontogeny in the San Francisco Estuary, California

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We utilized recently available sampling data (~1959-2012) from the Interagency Ecological Program and regional monitoring programs to provide a comprehensive description of the range and temporal and geographic distribution of longfin smelt (*Spirinchus thaleichthys*) by life stage within the San Francisco Estuary, California (Estuary). Within 22 sampling regions, we identified 357,538 survey events at 1,203 monitoring stations. A total of 1,035,183 longfin smelt (LFS) were observed at 643 stations (53%) in an area from Central San Francisco Bay (Tiburon) in the west, to Colusa on the Sacramento (Sacramento Valley region) in the north, Lathrop on the San Joaquin River (border of South Delta and San Joaquin River regions) to the east and South San Francisco Bay (Dumbarton Bridge) to the south, an area of approximately 137,500 ha. We found that LFS were frequently observed across a relatively large portion of their range, including East San Pablo Bay north into Suisun Marsh down through Grizzly Bay and all four regions of Suisun Bay through the Confluence to the Lower Sacramento River region. Unlike juvenile LFS, whose locations fluctuate between the bays and Suisun Marsh in relation to the low salinity zone, adults during the spawning period appeared to be not only in these locations but also in upper Delta reaches and also into San Francisco Bay, likely indicating that LFS spawning habitat may extend further upstream and downstream than LFS rearing habitat. The anadromous life stage declined in spring and mid-summer but increased throughout fall months across all areas, suggesting immigration and emigration through the Estuary. Longfin smelt appeared to migrate completely out of the lower rivers by July but some adults consistently remained in downstream Estuary areas, suggesting not all individuals demonstrate marine migration. This comprehensive data review provides managers and scientists an improved depiction of the spatial and temporal extent of LFS throughout its range within the Estuary and lends itself to future population analysis and restoration planning for this species.

Key words: Longfin smelt, San Francisco Estuary, distribution, *Spirinchus thaleichthys,* spatial analysis, life stage, observed presence

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The longfin smelt (*Spirinchus thaleichthys*) is a small (i.e., 90–110 mm standard length [SL] at maturity), semelparous, pelagic fish that has been observed in estuaries of the North American Pacific Coast, from Prince William Sound, Alaska to Monterey Bay, California with landlocked populations occurring in Lake Washington, Washington and Harrison Lake, British Columbia (McAllister 1963, Dryfoos 1965, Moulton 1979, Chigbu and Sibley 1994, Chigbu et al. 1998, Chigbu and Sibley 1998, Baxter 1999, Moyle 2002, Rosenfield and Baxter 2007). In California, the longfin smelt inhabits the San Francisco Estuary (Estuary), Humbodlt Bay, and Eel, Klamath and Smith rivers (Baxter 1999, CDFW 2009). According to Dryfoos (1965), the San Francisco Estuary (San Francisco Bay and Sacramento-San Joaquin River Delta) population has been considered the largest and southernmost self-sustaining population along the U.S. Pacific Coast, and has been considered to be genetically isolated from other populations (McAllister 1963, Moyle 2002). Once one of the most abundant species observed in Estuary surveys (Moyle et al. 2011), the Estuary longfin smelt (LFS) population has experienced dramatic declines over several decades (Rosenfield and Baxter 2007, Sommer et al. 2007, Baxter et al. 2008, Thomson et al. 2010), resulting in its March 2009 inclusion in the list of threatened pelagic fish species under the California Endangered Species Act (CDFW 2009).

A number of studies have investigated LFS distribution, habitat, and life history characteristics within the Estuary (Baxter 1999, Dege and Brown 2004, Hobbs et al. 2006, CDFW 2009, Moyle 2002, Matern et al. 2002, Rosenfield and Baxter 2007, Kimmerer et al. 2009, MacNally et al. 2010, Thomson et al. 2010). However, most of what has been learned about LFS (e.g., growth and in-river residence times) comes from other locations across its range, most often from Lake Washington (Dryfoos 1965, Eggers et al. 1978, Moulton 1979, Chigbu 1993, Chigbu and Sibley 1994a, 1994b, Chigbu and Sibley 1998, Chigbu et al. 1998, Chigbu 2000, Chigbu and Sibley 2002). Potential factors associated with abundance changes in Estuary fish species include stock-recruitment effects, increased mortality rates, reduced prey availability, overall shifts in fish assemblage composition (Feyrer et al. 2003, Sommer et al. 2007), and altered location of the 2 ppt isohaline in spring (known as "X2"; Thomson et al. 2010). Furthermore, the cascading impacts of aquatic species invasions can change food webs and make management actions for native fish more difficult (Feyrer et al. 2003).

Rosenfield and Baxter (2007) assessed the Estuary LFS population and addressed questions about distribution patterns and population dynamics. They used data from three long-term aquatic sampling programs of the California Department of Fish and Wildlife (CDFW; formerly California Department of Fish and Game) (i.e., Fall Midwater Trawl [FMWT], Bay Study Midwater Trawl [BMWT] and Otter Trawl [BOT]) and the University of California, Davis's Suisun Marsh survey that captured LFS from upstream of the Sacramento and San Joaquin River confluence to San Francisco Bay, to assess distribution and abundance, and tested for differences in abundance during pre-drought (1975–1986), drought (1987–1994) and post-drought (1995–2007) periods. Rosenfield and Baxter (2007) indicated significant declines in LFS abundance among these time periods, supporting their hypothesis that the Estuary's capacity to maintain pelagic fish species has been reduced over the past three decades. These results provide critically important information on distribution and abundance dynamics for LFS within the Estuary. However, questions remain about the full geographical extent and frequency of occurrence within the Estuary of each LFS life stage.

A full spatial depiction of where and when LFS are observed is vital to our understanding of critical management issues, including identifying important regions for each life stage, and potential opportunities for population conservation. In addition, when planning a conservation strategy for species protection and restoration, the spatial distribution of each population is required under federal and state statutes (Tracy et al. 2004, Carroll et al. 2006, Merz et al. 2011). Finally, considering data in a life stage-specific context provides for future assessment of stage-specific effects, supporting more practical and informative evaluations of specific cause–effect relationships, and will permit quantifying relationships between specific life stage transitions and environmental parameters (Merz et al. 2013). Interactive maps of some monitoring programs from CDFW have been publicly available for individually captured and monitored fish species, including LFS distribution within the Estuary (see http://www.dfg.ca.gov/delta). However, to our knowledge, no effort has been made to map LFS spatial range and distribution by life stages using available Estuary sampling data. The goal of this paper is to provide a comprehensive description of the range and temporal and geographic distribution of LFS by life stage within the Estuary.

Methods

Study area.—The San Francisco Estuary is the largest urbanized estuary (approximately 1,235 km^2) on the west coast of the United States (Lehman 2004, Oros and Ross 2005) (Figure 1). It consists of a series of basins with three distinct segments that drain an area of approximately 163,000 km^2 (40% of California's surface area): the Delta, Suisun Bay, and San Francisco Bay (van Geen and Luoma 1999, Sommer et al. 2007). The uppermost region of the Estuary is the delta of the Sacramento and San Joaquin rivers (Delta), a complex and meandering network of tidal channels around leveed islands (Moyle 2002, Kimmerer 2004). These two rivers narrow and converge before connecting with Suisun Bay, a large, shallow and highly productive expanse of brackish water that is strongly influenced by ebb and flood tides. Adjacent to Suisun Bay, Suisun Marsh, the largest contiguous brackish water wetland in the Estuary, provides a fish nursery area and habitat for migratory birds (Moyle 2002, Sommer et al. 2007). Suisun Bay is connected to San Pablo Bay — a northern extension of San Francisco Bay — through a long narrow channel called the Carquinez Strait. During high outflow years, the San Francisco Bay's salinity levels can be somewhat diluted by freshwater allowing freshwater fishes to move into tributary streams (Moyle 2002).

To qualitatively describe the spatial distribution of LFS, we delineated the Estuary into 22 regions (Figure 1, Table 1). These regions were South San Francisco Bay (1); Central San Francisco Bay (2); West San Pablo Bay (3); East San Pablo Bay (4); Lower Napa River (5); Upper Napa River (6); Carquinez Strait (7); Suisun Bay Southwest (8); Suisun Bay Northwest (9); Suisun Bay Southeast (10); Suisun Bay Northeast (11); Grizzly Bay (12); Suisun Marsh (13); Confluence (14); Lower Sacramento River (15); Upper Sacramento River (16); Cache Slough and Ship Channel (17); Lower San Joaquin River (18); East Delta (19);

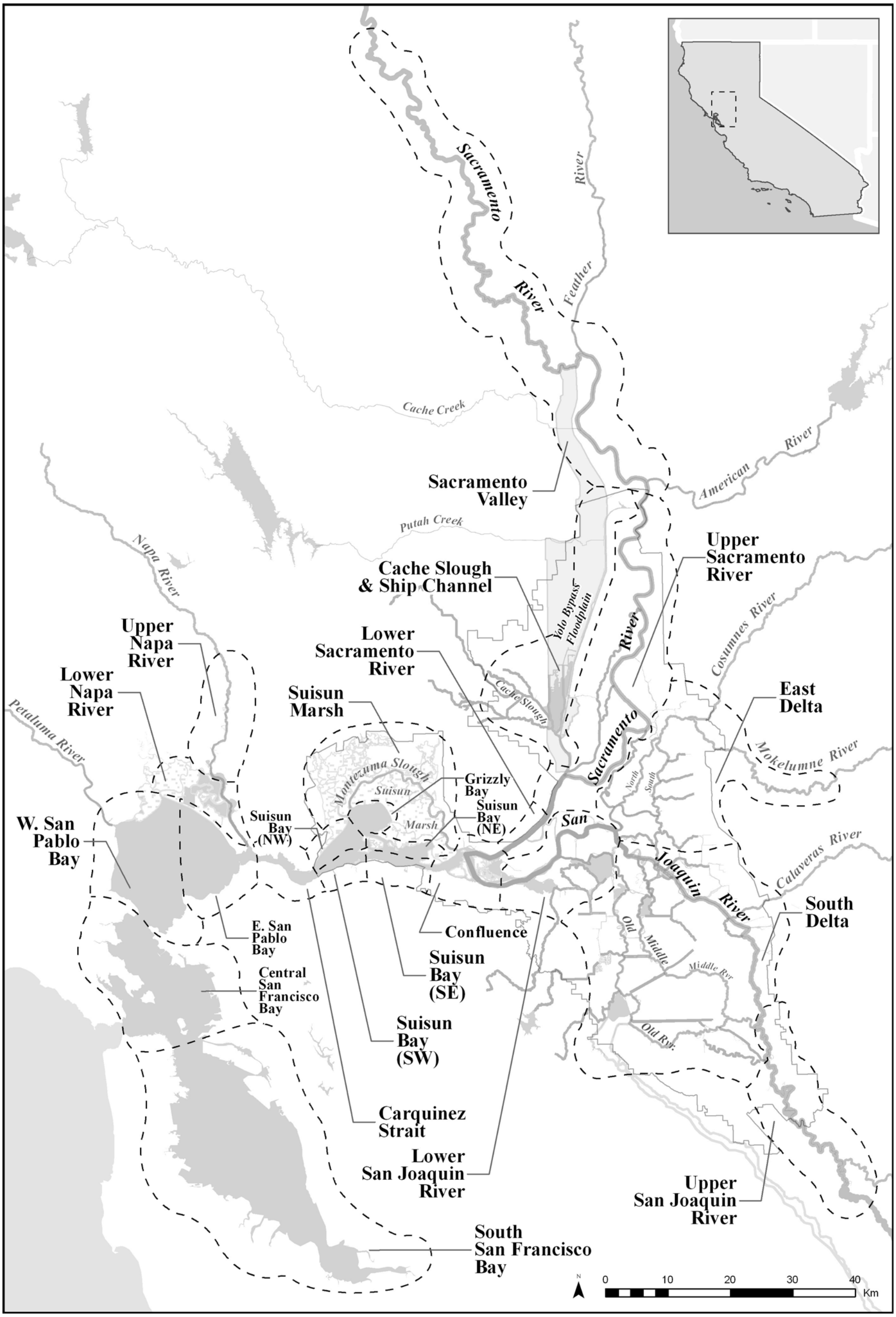

Figure 1.—A map of the San Francisco Estuary, California, and the 22 regions identified in this paper. Dashed lines indicate the estuary's regional delineations, which was based on the physical habitat and flow characteristics as well as physical landmarks (Kimmerer 2009, Merz et al. 2011).

Table 1.—Interagency Ecological Program (IEP) and Regional Monitoring Program (RMP) data that are publicly available, and were used to establish longfin smelt geographical extent range in the San Francisco Estuary, California.

Location	Survey Name	Gear Used	Study Period	Agency/ Sources	Program
Sacramento-San Joaquin Delta, Sacramento River, Chipps Island, San Francisco Estuary, Mossdale Crossing	Chinook and POD[a] Species	Beach Seine, Midwater Trawl, Kodiak Trawl	1976 - present	USFWS[b]	IEP
San Pablo Bay, Suisun Bay, Sacramento-San Joaquin Delta	20mm Survey	20-mm Plankton Net	1995 - present	CDFG[c]	IEP
Delta, Suisun Bay and Suisun Marsh	Smelt Larval Survey	Egg and Larval Net	2009 - present	CDFG[c]	IEP
San Pablo Bay, Suisun Bay, Sacramento-San Joaquin Delta, Sacramento Deep Water Ship Channel	Spring Kodiak Trawl	Kodiak Trawl	2002 - present	CDFG[c]	IEP
San Pablo Bay, Suisun Bay, Sacramento-San Joaquin Delta, Sacramento Deep Water Ship Channel	Fall Midwater Trawl	Midwater Trawl	1967 - present	CDFG[c]	IEP
San Pablo Bay, Suisun Bay, Sacramento-San Joaquin Delta, Sacramento Deep Water Ship Channel	Summer Tow Net Survey	Tow Net	1959 - present	CDFG[c]	IEP
San Francisco Bay, San Pablo Bay, Suisun Bay and downstream of Sacramento-San Joaquin Delta	San Francisco Bay Study	Midwater Trawl, Otter Trawl	1980 - present	CDFG[c]	IEP

TABLE 1 (continued).

Location	Survey Name	Gear Used	Study Period	Agency/ Sources	Program
San Francisco Bay, San Pablo Bay, Suisun Bay and downstream of Sacramento-San Joaquin Delta	San Francisco Plankton Net	Larval/Plankton Net	1980 - 1989	CDFG[c]	IEP
State Water Project and Central Valley Water Project	Fish Salvage Monitoring	Sieve Net	1993-present	CDFG[c]	IEP
Northern Sacramento-San Joaquin Delta	North Bay Aqueduct Survey	Larval Net	1995-2004	CDFG[c]	IEP
Suisun Marsh	Suisun Marsh Monitoring	Beach Seine, Larval Sled, Midwater Trawl, Otter Trawl	1980 - present	DWR[d] - UC Davis	IEP
Yolo Bypass	Yolo Bypass Study	Beach Seine	1998-2005	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Study	Fyke Net	1998	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Study	Fyke Trap	1999-2005	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Study	Purse Seine	1998	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Study	Rotary Screw Trap	1998-2005	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Floodplain Study	Rotary Screw Trap	1999-2002	Sommer et al. 2004	RMP

TABLE 1 (continued).

Location	Survey Name	Gear Used	Study Period	Agency/ Sources	Program
Sacramento-San Joaquin Delta	Littoral Fish Assemblages	Electrofishing	1980-2000	Brown & Michniuk 2007	RMP
Mokelumne River	Salmon and Steelhead Monitoring	Rotary screw trap	1993-2004	EBMUD[e]	RMP
Central Delta	Distribution of native and alien ichthyoplankton	Ichthyoplankton net	1990-2000	Grimaldo et al. 2004	RMP
Suisun Marsh	Native Alien Fishes	Beach Seine, Otter Trawl	1979-1999	Matern et al. 2002	RMP
Cosumnes River	Floodplain monitoring: Native and Alien Fish	Seine, Electrofishing	1998-2005	Moyle et al. 2007	RMP
Cosumnes River	Stream Evaluation	Seining, Rotary Screw Trap	1990-2000	Snider & Titus 2000	RMP
Cosumnes River	Larval Fishes on a restored Floodplain	Light traps, Dip nets	1999 - 2001	Crain et al. 2004	RMP
Lower Mokelumne River	Fish Community Survey	Seining, Backpack and Boat Electrofishing	1997-2004	Merz & Saldate 2000, 2005	RMP
Sacramento-San Joaquin Delta	Fishes of the Delta	Otter Trawl	1963-1964	Radtke 1966	RMP

TABLE 1 (continued).

Location	Survey Name	Gear Used	Study Period	Agency/ Sources	Program
Liberty Island	Spatial and temporal patterns by native and non-native fish larvae of a recently flooded island	Light traps, larval trawls	2003-2005	Marshall et al. 2006	RMP
South-east Suisun Bay, Confluence Sacramento and San Joaquin Rivers	Delta Mirant Power Plants	Sieve Net	2006 - 2008	Pittsburg and Contra Costa Power Plants	RMP
Lower Calaveras River	Calaveras River Barrier Removal	Beach Seine	2010	T.Kennedy[f]	RMP
West Delta	West Delta Survey	Beach Seine	2005-2006	T.Kennedy[f]	RMP

[a]POD: Pelagic Organism Decline
[b]USFWS: United States Fish and Wildlife
[c]CDFG: California Department of Fish and Game
[d]DWR: Department of Water Resources
[e]EBMUD: East Bay Municipal Utility District
[f]Fishery Foundation of California, personal communication

South Delta (20); Upper San Joaquin River (21); and Sacramento Valley (22). Delineation of Estuary regions was based on physical habitat, flow characteristics, and physical landmarks described in Kimmerer (2009) and Merz et al. (2011).

Monitoring data.—We synthesized all available information on Estuary fish monitoring surveys from the 1960s through 2012. These data were obtained directly from governmental and non-governmental entities, published and unpublished papers or reports, and through publicly available online databases of different surveys (i.e., http://www.water.ca.gov/iep/products/data.cfm). All data were reviewed and classified into either the Interagency Ecological Program (IEP) or the Regional Monitoring Program (RMP).

Interagency Ecological Program (IEP).—The Interagency Ecological Program (IEP) is a consortium of federal and state agencies that conducts long-term biological and ecological monitoring for use in Estuary management (Table 1). These monitoring surveys were from the United States Fish and Wildlife Service (USFWS) for Chinook salmon and pelagic organism decline (POD) species; CDFW for 20-mm plankton-net (20mm), Smelt Larval Survey (SLS), Spring Kodiak trawl (Kodiak), Fall midwater trawl (FMWT), Summer tow net, North Bay Aqueduct, Fish Salvage, San Francisco Bay Study's midwater trawl and Bay otter trawl (BOT), and San Francisco plankton net (Bay Plankton); and,California Department of Water Resources (CDWR) and the University of California Davis (UCD) for the Suisun Marsh monitoring. The IEP monitoring program is conducted using different sampling periods (e.g., biweekly, monthly), during different seasons and sampling frequency (e.g., Fall midwater trawl, Spring Kodiak trawl, Summer Tow Net), and on some occasions at a varying number of stations (i.e., supplemental stations are sometimes added for special study, or changes occurred depending on funding). Explicit, detailed descriptions for each IEP monitoring survey are available at the IEP website (http://www.water.ca.gov/iep/products/data.cfm).

Regional Monitoring Program (RMP).—Surveys conducted on a smaller geographic scale of the Estuary, and oftentimes in a shorter time period compared to the IEP surveys were classified in this study as RMP surveys (Table 1). The RMP surveys were carried out by various research institutions and governmental entities, and for a variety of project purposes (e.g. fish community survey, distribution and abundance, fish monitoring, floodplain monitoring). We summarized the number of sampling stations within each of the 22 identified regions, and identified the percentage of regions sampled by each survey (Table 2).

Observed geographic extent.—We utilized IEP and RMP survey records to identify the geographical extent of LFS within the Estuary. Following the approach of Merz et al. (2011) in developing the extent range of delta smelt (*Hypomesus transpacificus*) we used ArcGIS version 10 (ESRI, Redlands, CA) to plot all surveyed stations from the different monitoring programs from the 1960s through 2012 (Figure 2). If LFS were detected at least once at any given monitoring station, the species was designated as present at that site; otherwise the site was designated as "not observed" (Figure 2). We then developed a boundary around the stations where LFS were detected using a 1-km buffer (Merz et al. 2011, Graham and Hijmans 2006). We also calculated the total surface area of all waters within the range where LFS were observed using the ArcGIS 10 geoprocessing calculation tool (http://www.esri.com/software/arcgis/arcgis10). Note that the LFS geographical extent developed in this study did not consider the species to be absent if LFS were not observed, because of the lack of information on detection probability and different sampling frequencies for each survey gear type (Merz et al. 2011, Pearce and Boyce 2006).

Table 2.—The San Francisco Estuary regions and associated number of monitoring stations by sampling gears and monitoring surveys. "NS" = not sampled and "NI" = no regional sampling identified. San Francisco Estuary, California.

	Interagency Ecological Program Surveys										
	CDFG Monitoring Surveys								USFWS	DWR-UC Davis	Regional Surveys
Region	Spring Kodiak Trawl	20mm Survey	Summer Tow Net Survey	Delta Fall Midwater Trawl	Smelt Larva Survey	Smelt Larval Survey	SF Bay Study	Fish Salvage	Chinook and POD Surveys	Suisun Marsh Surveys	
South San Francisco Bay	NS	NS	NS	1	NS	NS	48	NS	NS	NS	NI
Central San Francisco Bay	NS	NS	NS	2	NS	NS	32	NS	10	NS	NI
West San Pablo Bay	NS	NS	3	22	NS	NS	20	NS	4	NS	NI
East San Pablo Bay	NS	7	8	17	NS	7	20	NS	4	NS	NI
Lower Napa River	2	3	4	2	NS	3	NS	NS	0	NS	NI
Upper Napa River	4	7	1	NS	NS	7	NS	NS	0	NS	NI
Carquinez Strait	1	1	3	8	1	1	8	NS	6	NS	NI
Suisun Bay (SW)	1	1	1	5	1	1	4	NS	1	NS	NI
Suisun Bay (NW)	1	1	1	6	1	1	12	NS	0	NS	NI
Suisun Bay (SE)	2	2	2	8	2	2	4	NS	2	NS	1
Suisun Bay (NE)	2	2	2	5	2	2	4	NS	0	NS	NI
Grizzly Bay	1	1	1	4	1	1	4	NS	0	NS	NI
Suisun Marsh	5	3	3	5	3	3	NS	NS	9	93	10
Confluence	4	5	4	13	5	5	8	NS	11	NS	41
Lower Sacramento	4	4	3	4	4	4	6	NS	0	NS	36
Upper Sacramento	4	3	2	13	1	1	6	NS	51	NS	10
Cache Slough/Ship Channel	5	11	1	10	2	1	0	NS	11	NS	17
Lower San Joaquin River	6	6	4	13	5	6	12	NS	15	NS	34
East Delta (Mokelumne)	5	1	2	8	1	1	0	NS	26	NS	51
South Delta	6	9	7	15	6	6	0	3	50	NS	15
Upper San Joaquin River	NS	NS	NS	NS	NS	NS	0	NS	23	NS	2
Sacramento Valley	NS	NS	NS	NS	NS	NS	0	NS	53	NS	6
Total number of stations surveyed	53	67	52	161	35	52	188	3	276	93	223
Percent of regions represented	73	77	82	86	64	77	86	5	95	5	50

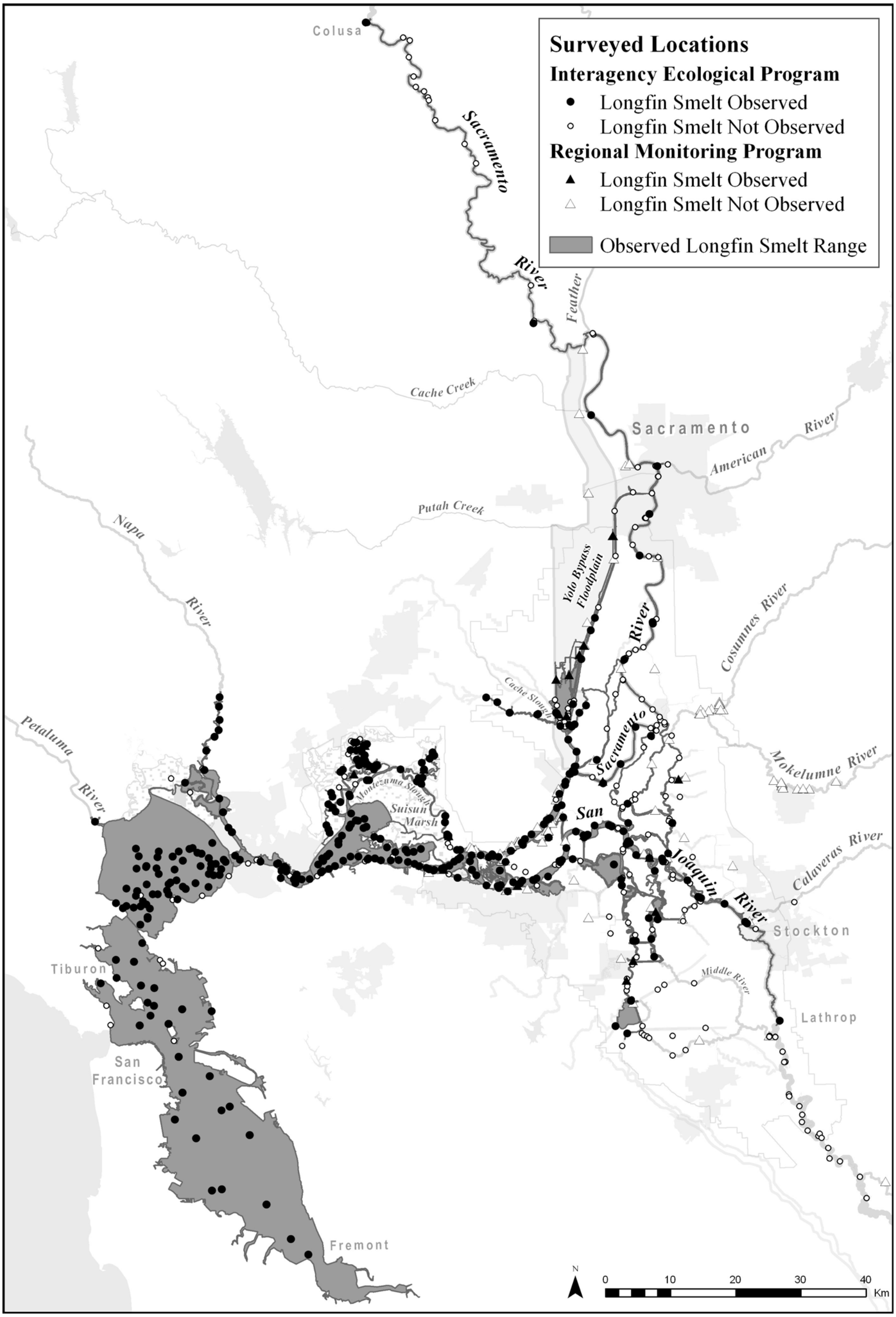

Figure 2.—The geographical extent range and observations of longfin smelt at monitoring stations of Interagency Ecological Program (IEP) survey and Regional Monitoring Program (RMP) surveys. Circles indicate IEP stations where longfin smelt were observed (closed) or not observed (open). Triangles indicate RMP stations where longfin smelt where observed (closed) or not observed (open). The dark gray represents the observed longfin smelt range in the San Francisco Estuary, California.

TABLE 3.—Delineations of longfin smelt lifestages by time-period, sizes, IEP sampling gears and sampling periods, and descriptions used for frequency of detection analysis in the San Francisco Estuary, California.

Life Stage	Time Period	Sizes	Sampling Study[1]	Sampling Years	Sampling Months	Description
Larva	Jan -June	<16 mm	Bay Plankton 20mm SLS	1980-1989 1995-2011 2009-2011	Jan-June Mar-May Jan-Mar	The larval phase begins after hatching and ends when resorption of the yolk-sac and fin formation are nearly complete (< 16mm; Wang 1991).
Juvenile	Apr-Oct	Baxter (2009) monthly cutoffs	BOT 20mm FMWT	1980-2011 1995-2011 1980-2011	Apr-Oct Apr-Jul Sep-Oct	This phase begins when fin formation is nearly complete (16mm; Wang 1991), and encompasses the first major growth period of longfin smelt (Moyle 2002).
Sub-adult	Nov-Apr	Baxter (2009) monthly cutoffs	BOT FMWT Kodiak	1980-2011 1980-2011 2002-2011	Nov-Apr Nov-Dec Jan-Apr	Period of slow-growth during winter months (Moyle 2002) prior to anadromous migration.
Anadromous	Mar-Jan	Baxter (2009) monthly cutoffs	BOT	1980-2011	Mar-Jan	Encompasses second major growth period (Moyle 2002) and period of anadromous outmigration for a portion of the population towards the ocean from March through August and immigration upstream from September through January (Rosenfield and Baxter 2007).
Adult	Dec-May	Baxter (2009) monthly cutoffs	BOT Kodiak	1980-2011 2002-2011	Dec-May Jan-May	Encompasses spawning period of adult longfin smelt (Moyle 2002). Gravid females are detected between late-fall and winter (Rosenfield 2010; Moyle 2002)

[1]Bay Plankton = San Francisco Plankton Net Survey, 20mm = 20mm survey, SLS = Smelt Larval Survey, BOT = San Francisco Bay Study Otter Trawl, FMWT = Fall Midwater Trawl, and Kodiak Trawl = Spring Kodiak Trawl.

Life stage determinations.—We delineated life stages based on month and fish-size (Table 3, Figure 3). We adapted LFS life-stage definitions and monthly cut-offs established by DRERIP (Delta Regional Ecosystem Restoration Implementation Plan; Rosenfeld 2010). LFS life stages used in this study are *larva, juvenile, sub-adult, anadromous,* and *adult* (Table 3, Figure 3). Unlike DRERIP (Rosenfield 2010), we defined an anadromous stage to highlight the LFS migratory period (Rosenfield and Baxter 2007), and defined an adult life stage instead of "sexually mature adult" due to unavailability of sexual maturation data to differentiate premature versus mature LFS. We also did not evaluate the egg life stage as there are no Bay-Delta surveys (e.g., plankton net) that monitor LFS eggs. Because the

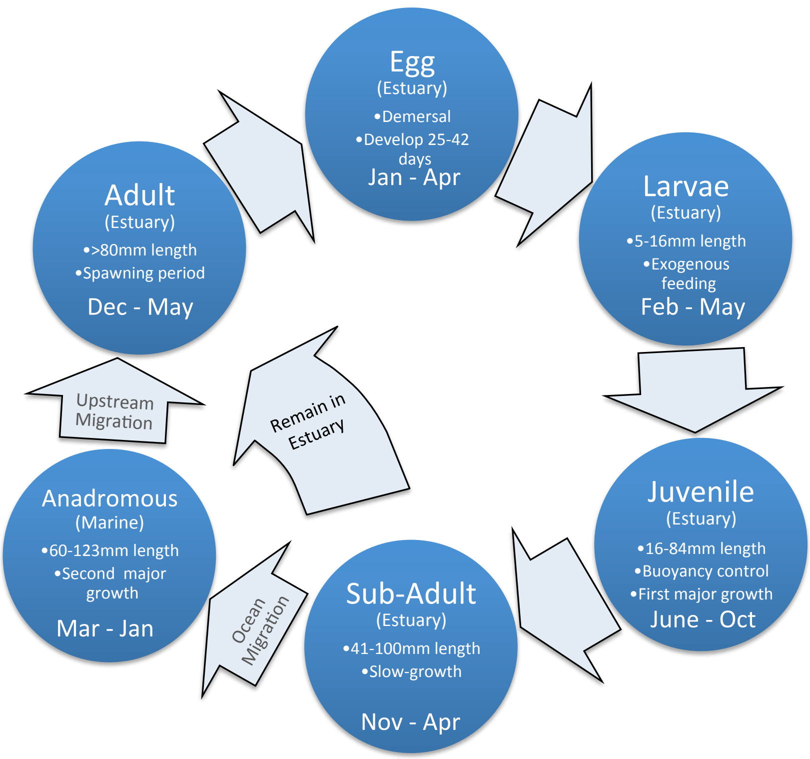

Figure 3.—Life cycle of longfin smelt, adapted from the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) Conceptual Models. Available at: http://www.dfg.ca.gov/erp/cm_list.asp

LFS life cycle spans 3 calendar years, we used the monthly fork length criteria defined by Baxter (1999) to separate LFS of each age (years 1, 2, or 3; Table 4). The only modification of Baxter's (1999) criteria is the addition of a maximum length cutoff of 15 mm for larva, which is the length at which yolk-sac resorption and fin formation are nearly complete (Wang 1991; Table 4).

Table 4.—Length (mm) delineations of longfin smelt by year, life stage, and month used in frequency of detection analyses. Monthly length cut-offs from Baxter (1999), except for 16-mm cutoff for larva used to separate larvae and juveniles. San Francisco Estuary, California.

Year 1			Year 2			Year 3		
Life Stage (s)	Month	FL (mm)[1]	Life Stage (s)	Month	FL (mm)	Life Stage (s)	Month	FL (mm)
Larva	Jan	<16	Sub-adult	Jan	40-89	Anadromous, Adult	Jan	>89a
Larva	Feb	<16	Sub-adult	Feb	42-92	Adult	Feb	>92
Larva	Mar	<16	Sub-adult, Anadromous	Mar	46-95[2]	Adult	Mar	>95
Larva, Juvenile	Apr	<16, 16-51	Sub-adult, Anadromous	Apr	52-99[2]	Adult	Apr	>99
Larva, Juvenile	May	<16, 16-58	Anadromous	May	59-104	Adult	May	>104
Larva, Juvenile	Jun	<16, 16-66	Anadromous	Jun	67-107			
Juvenile	Jul	<71	Anadromous	Jul	71-110			
Juvenile	Aug	<75	Anadromous	Aug	75-113			
Juvenile	Sep	<80	Anadromous	Sep	80-116			
Juvenile	Oct	<83	Anadromous	Oct	83-119			
Sub-adult	Nov	<85	Anadromous	Nov	85-122			
Sub-adult	Dec	<87	Anadromous, Adult	Dec	87-124[2]			

[1] FL = Fork length
[2] Length range applied to both life stages

During the first year of life, LFS transition from egg (December–April; Rosenfield 2010) to free-floating, endogenously nourished larva (January–June; Rosenfield 2010), to juvenile when the first major growth period occurs (April–October; Moyle 2002), and to sub-adult when growth slows during winter months prior to anadromous migration (November–December; Moyle 2002). Unlike DRERIP (Rosenfield 2010), which describes the juvenile stage as extending until the end of the first year of life, we cut off the life stage in October, at the end of the first major growth period as described by Moyle (2002). Additionally, instead of the sub-adult stage extending from the beginning of the second year of life to maturation (Rosenfield 2010), we defined the sub-adult period as the winter, slow-growth period between the juvenile and anadromous life stages.

The second and third years of life begin with the slow-growth period of sub-adults continuing into spring (January–April; Moyle 2002). Next, a portion of the LFS population undertakes an anadromous migration (emigration) towards the ocean, followed by return upstream migration (immigration) during March–January (Rosenfield and Baxter 2007), while remaining LFS continue to rear in the Estuary. This summer and fall period encompasses the second major LFS growth period (Moyle 2002). Finally, the LFS adult life stage encompasses the spawning period during December–May (Rosenfield 2010; Moyle 2002).

Frequency of detection. —Because each type of gear selectively captures different LFS life stages and is deployed in different seasons, we used data from six IEP monitoring surveys (Bay Plankton, 20mm, SLS, BOT, Kodiak trawl, and FMWT) to examine LFS spatial distribution across life stages within the Estuary (Table 3). For each life stage, only data from each gear type that fell within delineated months for that life stage were used (Table 3). We used LFS catch data for years 1980 to 2011 for all surveys except for 20mm, SLS and Kodiak, where sampling started in 1995, 2009 and 2002 respectively (Table 3). We included only sampling stations that were consistently surveyed, as determined by identifying stations that were sampled ≥90% of the time across all years (Merz et al. 2011).

The average annual LFS detection frequency at consistently surveyed stations for each life stage (except anadromous stage) in each region was calculated as

$$P_{lrpy} = (S_{lrpy} / N_{rpy}) * 100$$

where P_{lrpy} represents the percent of unique numbers of sampling events in which the life stage *l* LFS were captured in each region *r* during time period *p* and year *y*; S_{lrpy} represents the number of sampling events in a region *r* when the life stage *l* LFS were captured during time period *p* and year *y*; and, N_{rpy} represents the total number of sampling events from region *r* during time period *p* and year *y*. Next, the average annual frequency of observation for LFS by life stage and region was calculated as a simple average over all years. Results from LFS detection frequencies by life stage (except anadromous stage) and region were mapped using ArcGIS 10.

Because a portion of the Estuary LFS population migrates during the anadromous life stage, detection frequency was calculated monthly within regions to better depict LFS migratory movements. Similar methods employed for the other life stages were used to calculate detection frequency for the anadromous life stage, except time period *p* was monthly, and regions *r* were grouped into four areas (Lower Rivers, Suisun, East Bay, and West Bay) to better visualize anadromous behavior. Lower Rivers covers all regions from Sacramento Valley downstream to the Lower Sacramento River and San Joaquin River regions, Suisun covers the Confluence and all Suisun Bay regions, East Bay covers Carquinez Straight downstream to East San Pablo Bay, and West Bay covers the West San Pablo Bay and San Francisco Bay regions.

Results

Within the 22 Estuary regions, we identified 357,538 survey events (a sampling event at a given location and time) at 1,203 monitoring stations. Of these, 343,482 (96%) were from IEP and 14,056 (4%) were from regional monitoring programs (Table 1). The program or survey with the single greatest number of monitoring stations was the Chinook and POD (276), followed by the SF Bay Study (188), FMWT (161), Suisun Marsh surveys (93), 20mm Survey (67), and Spring Kodiak Trawl (53) (Table 2). A total of 1,035,183 LFS were observed at 620 of the 980 (63%) IEP monitoring stations and at 23 of the 223 (10%) regional monitoring stations identified in this study.

Observed geographic extent.—LFS were observed in all 22 regions covering an area of about 137,500 ha (Figure 2). Observations occurred as far west as Tiburon in Central San Francisco Bay, north as far as the town of Colusa on the Sacramento River (Sacramento Valley region), east as far as Lathrop on the San Joaquin River (border of South Delta and San Joaquin River regions), and south as far as the Dumbarton Bridge in South San Francisco Bay. Tributary observations included the Napa and Petaluma rivers, Cache Slough, and the Mokelumne River to the east. LFS were also observed in seasonally-inundated habitat of the Yolo Bypass.

No single IEP monitoring program sampled all 22 regions (Table 2) that make up the observed extent of LFS range, and three regions had no IEP sampling. The Chinook and POD surveys had the highest coverage (95% of regions each). The FMWT and SF Bay surveys covered 86% of the regions each, while coverage among the other IEP surveys ranged from 5 to 82%. Each RMP survey typically covered less than 4% of the observed extended range.

Distribution by life stage.— For all life stages, LFS were observed most frequently throughout a relatively large portion of their range – from East San Pablo Bay north into Suisun Marsh down through Grizzly Bay, and all four regions of Suisun Bay through the Confluence (Figure 4, Figure 5). In addition to being frequently detected in the central

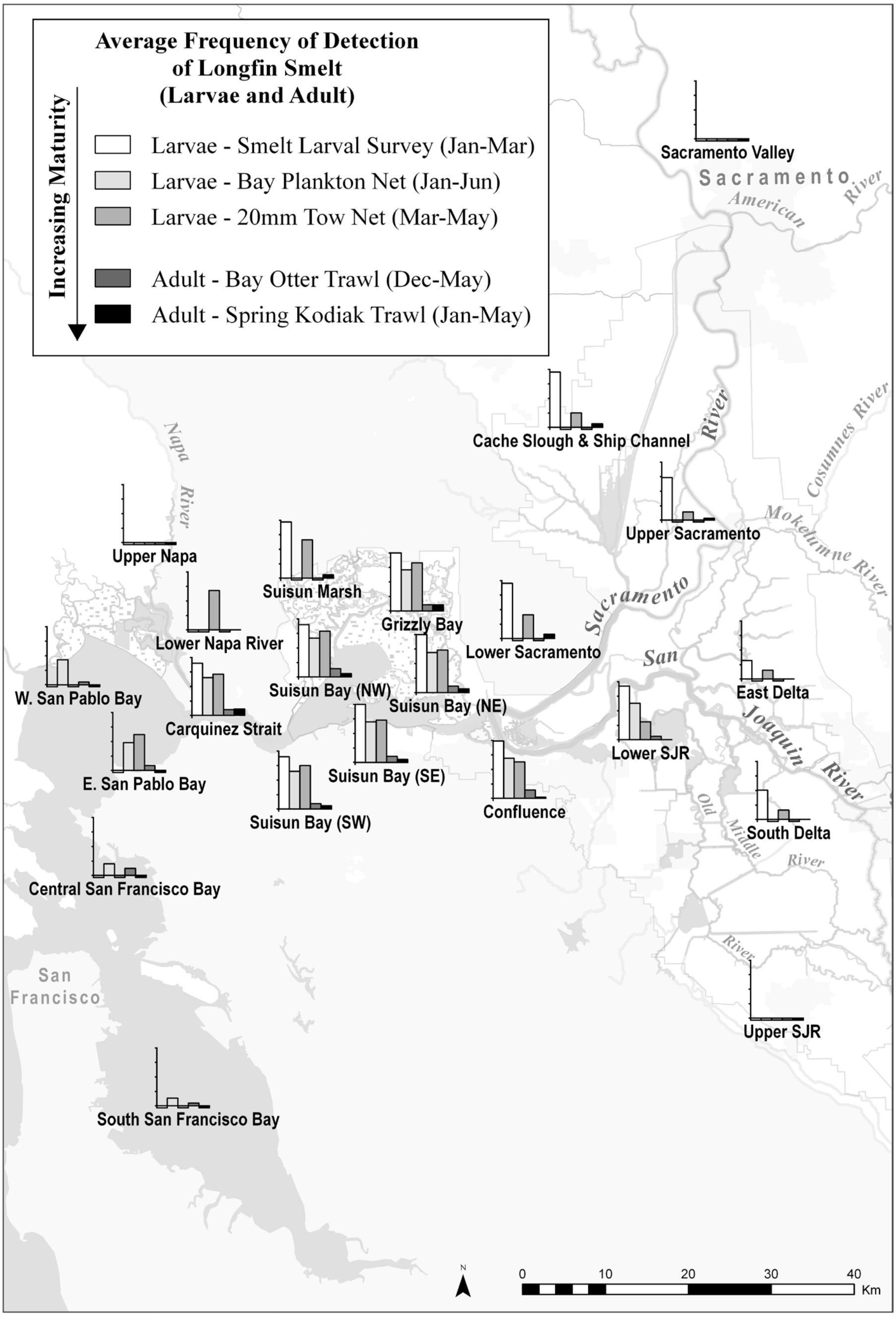

FIGURE 4.—Average annual frequency of longfin smelt detection (%) for larvae and adult lifestages by region and Interagency Ecological Program survey type. The percent of sampling events where longfin smelt was observed over the total number of sampling events within a region. Regions where the percent frequency of detection for a given life stage was zero is indicated by no data column/bar being present in the bar graph. Regions that were not sampled for a given life stage are indicated by a data column/bar suspended slightly below the x-axis. Y-axis ticks indicate percent frequencies of 0, 25, 50, 75 and 100 percent.

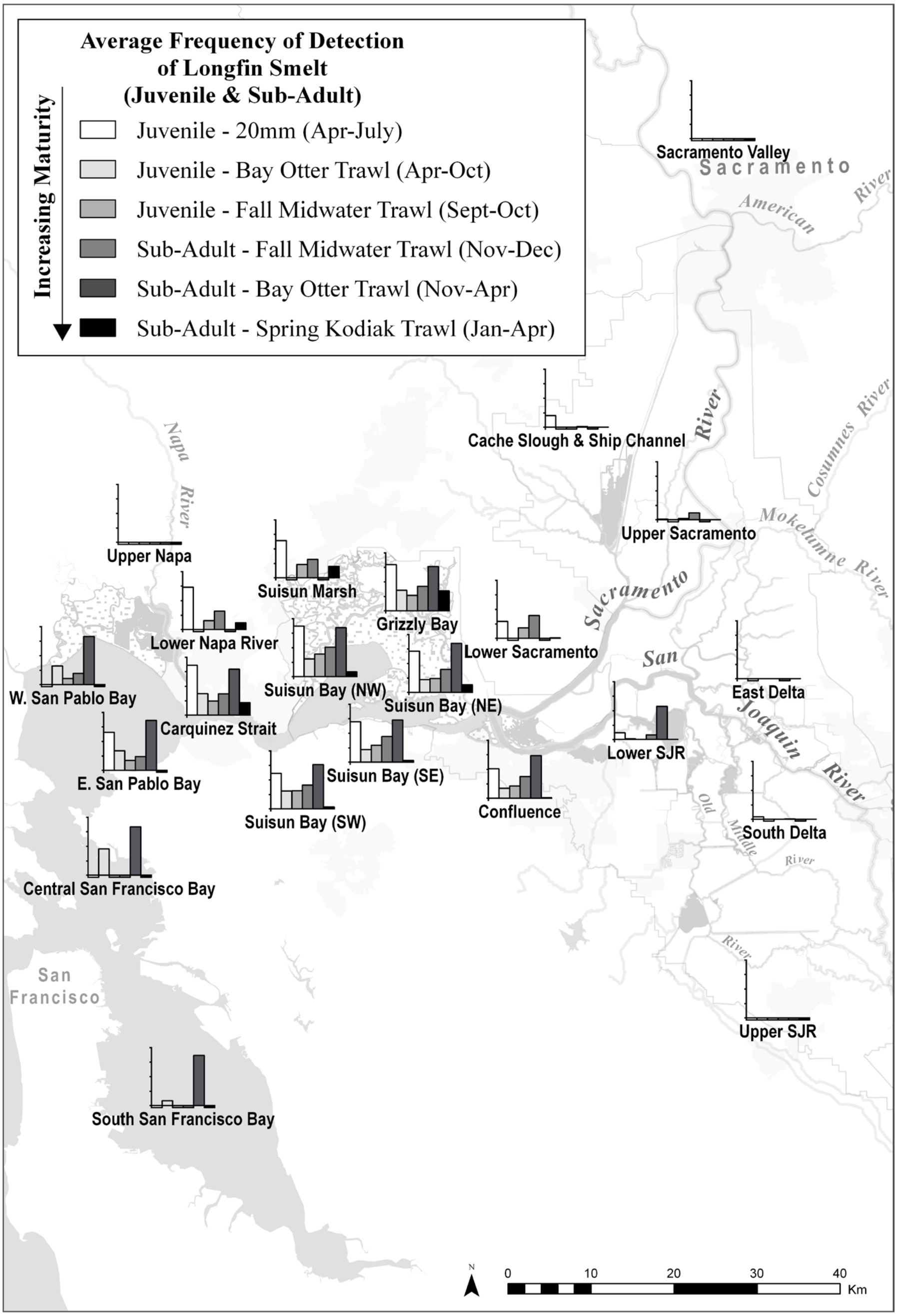

FIGURE 5.—Average annual frequency of longfin smelt detection (%) for juvenile and sub-adult life stages by region and Interagency Ecological Program survey type. The percent of sampling events where longfin smelt was observed over the total number of sampling events within a region. Regions where the percent frequency of detection for a given life stage was zero is indicated by no data column/bar being present in the bar graph. Regions that were not sampled for a given life stage are indicated by a data column/bar suspended slightly below the x-axis. Y-axis ticks indicate percent frequencies of 0, 25, 50, 75 and 100 percent.

regions (from Carquinez Straight upstream to the Confluence), adult and larvae were both detected relatively frequently upstream of the Confluence (Figure 4, Table 5). Larvae were detected greater than 73% of the time in the Lower Sacramento, Upper Sacramento, Cache Slough and Ship Channel, and Lower San Joaquin regions, and greater than 31% of the time in the East Delta and South Delta regions during the SLS (Figure 4, Table 5). Although detected at a much lower frequency across all regions than larvae, adults were also detected in South San Francisco Bay, upstream in Cache Slough and Ship Channel, and Upper Sacramento regions.

Unlike adult and larval life stages, juvenile and sub-adult life stages were not frequently detected upstream of the Confluence, and instead were more frequently detected in the most downstream Bay regions (Figure 5, Table 5). During BOT sampling, juveniles and sub-adults were detected in greater than 32% of sampling events in both San Pablo Bay regions and Central San Francisco Bay. Sub-adults were also detected at a relatively high frequency (86.6%) in the South San Francisco Bay during BOT sampling (Figure 5, Table 5).

During the anadromous life stage, LFS exhibited declining average frequency of detection during the spring months and into mid-summer, followed by increasing average detection frequency throughout the fall months across all Estuary areas during BOT sampling (Figure 6). The lowest average detection frequencies for each area occurred at successively

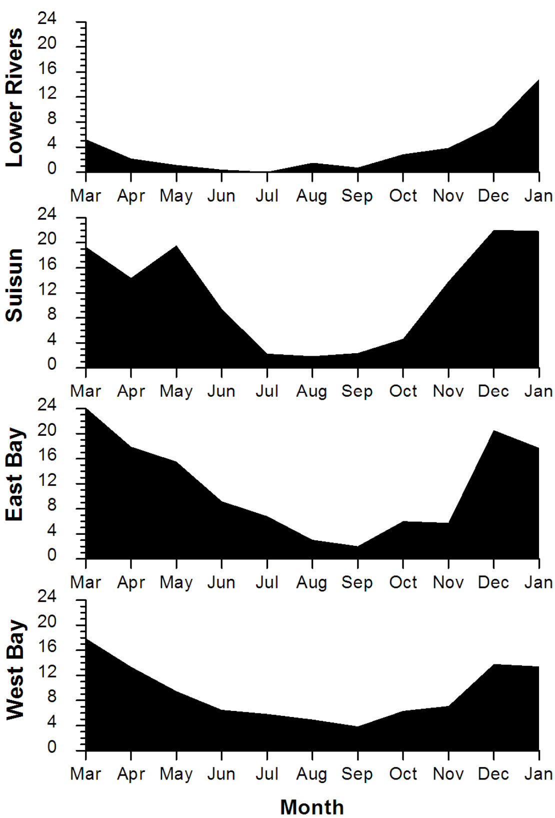

FIGURE 6.—Average annual frequency of longfin smelt detection (%) for the anadromous life stage by month and area for the years 1980–2011. Frequency of detection was calculated as the percent of sampling events where longfin smelt were observed over the total number of sampling events within an area. Lower Rivers covers all regions from Sacramento Valley downstream to the Lower Sacramento and San Joaquin River regions, Suisun covers the Confluence and all Suisun Bay regions, East Bay covers Carquinez Straight downstream to East San Pablo Bay, and West Bay covers West San Pablo Bay and San Francisco Bay regions.

Table 5.—Average frequency (%) of longfin smelt detection by life-stage across all years, Interagency Ecological Program monitoring program, and region in the San Francisco Estuary, California.

	Life-Stage										
	Larvae				Juvenile			Sub-Adult		Adult	
Monitoring Program[1]	BP	20mm	SLS	BOT	20mm	FMWT	BOT	FMWT	Kodiak	BOT	Kodiak
Years of data used	80-89	95-11	09-11	80-11	95-11	80-11	80-11	80-11	02-11	80-11	02-11
Time Period	Jan-Jun	Mar-Jun	Jan-Mar	Apr-Oct	Apr-Jul	Sep-Oct	Nov-Apr	Nov-Dec	Jan-Apr	Dec-May	Jan-May
Region											
South San Francisco Bay	13.0	ns[2]	ns	8.2	ns	ns	86.6	ns	ns	4.7	ns
Central San Francisco Bay	20.0	ns	ns	45.6	ns	ns	83.6	ns	ns	12.1	ns
West San Pablo Bay	43.0	ns	ns	32.1	ns	10.4	82.6	19.1	ns	4.7	ns
East San Pablo Bay	48.0	62.0	ns	33.5	65.4	17.0	85.9	23.4	ns	8.7	ns
Lower Napa River	ns	68.0	ns	ns	73.0	15.6	ns	31.8	11.7	ns	0.0
Upper Napa River	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Carquinez Strait	65.0	71.0	90.0	37.0	86.1	24.2	79.2	36.6	21.7	9.7	11.0
Suisun Bay (SW)	65.0	75.0	90.0	30.7	61.0	31.1	76.0	40.9	3.3	9.4	5.8
Suisun Bay (NW)	67.0	79.0	90.0	30.7	87.1	39.1	84.6	50.9	8.3	14.1	5.8
Suisun Bay (SE)	70.0	73.0	100.0	21.8	69.9	29.3	72.6	44.2	2.9	10.3	5.3
Suisun Bay (NE)	69.0	73.0	100.0	21.8	70.9	23.8	84.4	39.5	12.9	11.1	6.3
Grizzly Bay	71.0	83.0	100.0	35.1	79.3	26.3	76.2	42.1	34.2	10.7	10.7
Suisun Marsh	ns	66.0	96.7	ns	64.4	22.9	ns	31.8	19.7	ns	5.8
Confluence	69.0	63.0	99.0	16.8	50.7	21.0	73.3	37.3	0.8	14.4	2.2
Lower Sacramento	ns	41.0	95.4	ns	29.2	18.0	ns	39.5	0.8	ns	7.7
Upper Sacramento	ns	14.0	73.3	ns	0.9	2.0	ns	11.9	0.0	ns	3.3
Cache Slough & Ship Channel	ns	25.0	95.4	ns	19.8	ns	ns	0.8	0.0	ns	6.4
Lower San Joaquin River	63.0	31.0	92.3	1.0	11.5	0.2	57.1	8.0	0.0	5.9	0.0
East Delta (Mokelumne)	ns	15.0	31.7	ns	0.0	0.0	ns	0.0	0.0	ns	0.0
South Delta	ns	16.0	50.6	ns	4.0	0.0	ns	0.5	0.0	ns	0.0
Upper San Joaquin River	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sacramento Valley	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] BP = San Francisco Bay Plankton Net Survey, 20mm = 20mm survey, SLS = Smelt Larval Survey, BOT = San Francisco Bay Study Otter Trawl, FMWT = Fall Midwater Trawl, and Kodiak Trawl = Spring Kodiak Trawl.
[2] "ns" indicates no survey conducted or regions which had inconsistently surveyed stations across all years, hence, excluded in calculating frequency of detection

later months moving downstream (Lower Rivers = July, Suisun = August, East and West Bay = September), possibly indicating downstream emigration through each Estuary area. Although LFS appeared to migrate completely out of the Lower Rivers area with an average detection frequency of zero being observed in July, monthly average detection frequencies did not drop below 2% for any Estuary area downstream.

Discussion

Observed geographic extent.—Effective conservation programs typically require a description of a species' geographical distribution or use of habitats (Pearce and Boyce 2006). Examples include reserve design (Araujo & Williams 2000), population viability analysis (Boyce et al. 1994; Akcakaya et al. 2004) and species or resource management (Johnson et al. 2004). Techniques characterizing geographical distributions by relating observed occurrence localities to environmental data have been widely applied across a range of biogeographical analyses (Guisan and Thuiller 2005). A general description of LFS distribution by occurrence was described by Moyle (2002), Rosenfield and Baxter (2007), and Rosenfield (2010); all indicated that during the LFS life cycle, it used the entire Estuary from the freshwater Sacramento-San Joaquin Delta downstream to South San Francisco Bay, and out into coastal marine waters. Regarding the extent of LFS range, those fish have been observed in a considerable portion of the western Delta, and upstream of the Feather River confluence with the Sacramento River, and the San Joaquin River to its confluence with the Tuolumne River.

Similar to the treatment of delta smelt by Merz et al. (2011), we utilized recently available data from the 20-mm and Kodiak, and Chinook and POD surveys together with other IEP and regional monitoring programs to provide information on areas of the Estuary where identified LFS life stages have been observed. While our study found similar extent of LFS distribution within the Estuary when compared with Moyle (2002), Rosenfield and Baxter (2007), and Rosenfield (2010), we observed the range of LFS extending further north on the Sacramento River, in the Petaluma River to the west, and extensions upstream on the Napa River and northern Suisun Marsh, covering an estimated area of 137,500 ha. Observations at the most upstream sampling stations in the Napa and Petaluma rivers indicated that the extent of LFS distribution in these locations remains unknown. Expanding research into these watersheds may provide insight into habitat management and future restoration for native estuarine fish assemblages including LFS (Gewant and Bollens 2012).

Distribution by life stage.— We found that LFS were frequently observed across a relatively large portion of their range, including East San Pablo Bay north into Suisun Marsh down through Grizzly Bay, and all four regions of Suisun Bay through the Confluence to the Lower Sacramento River region. Furthermore, we were able to identify regions such as Suisun Marsh and San Pablo Bay where the frequency of occurrence was relatively high in each life stage, suggesting a continuous Estuary presence. As with other anadromous species, it is likely that the mosaic of Estuary habitats provides benefits to LFS at various stages during their life history and development (Simenstad et al. 2000, Able 2005).

Identifying nursery habitats is important to conservation, as these habitats disproportionately contribute individuals to adult populations of a species (Hobbs et al. 2010). Longfin smelt are anadromous, and are known to spawn in freshwater and then move seaward for rearing. Longfin smelt have been collected in the Gulf of Farallones (Baxter

1999, CDFW 2009) and spawning has been documented in freshwater Estuary tributaries (USFWS 1996). Previous research has indicated a specific "low salinity zone" of the Estuary that serves as nursery habitat for various species (Jassby et al. 1995); in particular, the Suisun Bay has been identified as critical nursery habitat providing ideal LFS feeding and growing conditons (Hobbs et al. 2006). By utilizing all available survey data at once, we developed maps that provide evidence of a widespread rearing zone extending across the Estuary and spanning San Pablo and San Francisco bays as far upstream as the Lower Sacramento River and Lower San Joaquin River regions.

We found that both adult and larval LFS were detected relatively frequently in the uppermost regions of the Estuary (upstream of Confluence), unlike the juvenile and sub-adult life stages, likely indicating that LFS spawning habitat extends further upstream into freshwater areas than LFS rearing habitat. Unlike juvenile LFS, whose locations fluctuate between the bays and Suisun Marsh in relation to the low salinity zone (Dege and Brown 2004; Bennett et al. 2002), spawning adults appear to be not only in these locations but also to disperse into upper Delta reaches and into San Francisco Bay as well. However, adult presence in the San Francisco Bay during the spawning period likely relates to years with high Delta inflows, when low salinity habitat shifted westward. Spawning of LFS in high salinity habitat is unlikely, as such an occurrence would be maladaptive due to the low tolerance of LFS larvae to high salinity (Baxter 2009). Kimmerer et al. (2009) found larvae and juveniles most abundant at 2 ppt, and declined rapidly as salinity increased to 15 ppt.

Similar to findings of Rosenfield and Baxter (2007), we found evidence of LFS exhibiting anadromous behavior during their second year of life. The relative detection frequency of sub-adult LFS declined throughout the spring and summer months, possibly indicating a marine migration outside of the sampling area. A subsequent increase in LFS detection frequency during their second fall and winter indicates a migration back into the sampling area prior to the spring spawning season. This is consistent with an observation by Moyle (2002) that LFS gradually migrate upstream during fall and winter, as yearlings prepare for spawning. Rosenfield and Baxter (2007) also observed a decrease in LFS detection frequency and distribution after their first winter (sub-adults), followed by an increase during the second winter (adults). Although these results indicate that the marine residency of LFS is relatively brief (up to 6 to 8 months), annual variability in the duration of marine migrations remains unknown, as do the factors affecting timing of immigration and emigration (Rosenfield and Baxter 2007). There also appears to be a portion of sub-adults that do not fully leave the Estuary, suggesting a diversity in life-history strategies. A better understanding of the potential benefits of anadromy verses Estuary residency, interaction of Estuary LFS with other populations, and environmental mechanisms behind LFS anadromy appears relevant to the long-term management of this population.

Although each of the current Estuary sampling protocols suffered from one or more notable shortcomings (Bennett 2005), existing data can be explored to offer groundwork for understanding Estuary fisheries resources and specifically LFS geographic range by life stage. A better understanding of LFS spatial distribution informs conservation efforts by serving as an illustration of habitat use. Restoration strategies must include an understanding of habitat functions to effectively contribute to LFS recovery within the Estuary. There is a specific need for strategic planning in rehabilitation efforts. Some researchers have approached the question of relative influence of biological and physical factors on population abundance and the impact to conservation, and suggested mechanisms of population recovery (Mace et al. 2010). Researchers interested in developing a self-sustaining system have argued for the recovery of key processes that maintain habitat conditions (Beechie et al. 2010).

Understanding that critical differences exist in Estuary habitat value for each life stage among sites and time periods supports the use of spatial analysis in Estuary conservation and restoration planning. Exploring existing LFS data from various studies and databases, and making additional investigations into population demographics (i.e., timing or location of declines), environmental factors demonstrating the greatest influence on population abundance (e.g., temperature, water quality, prey density, etc.), and affinity analyses to assess habitat preference would provide a solid basis to address key issues. Longfin smelt are vulnerable to a large number of environmental stressors within the Estuary (Moyle 2002; Baxter et al. 2008; Healey et al. 2008) and individual stressors may have more or less significance for a species or population based on the manifestation of the stressor and proximity to that species (Tong 2001, Armor et al. 2005). Therefore, further investigations using an affinity analysis are warranted to understand more about life stage-specific key habitat attributes.

In this study, we have demonstrated the extent of LFS range is greater than previously reported (Rosenfield and Baxter 2007). We have provided additional information on distribution and detection frequencies of the Estuary population of LFS by life stage and season to support conservation planning by identifying areas to focus further study. While this analysis documents Estuary areas utilized by LFS, more work is needed to better understand the relationship between mapped spatial distribution and habitat use and productivity.

Long-term average distributional patterns are affected by inter-annual population shifts (e.g., eggs and larvae as per Dege and Brown 2004). Sampling program duration may further affect the percentage of detections at specific sites. Additionally, if the population range has shifted over time, then sampling that occurred only in recent years (e.g. in the northern Delta as the Bay Study sampling program expanded) might reveal a different pattern than if all the sampling localities in this study had been monitored over 50 years. This suggests further investigation into LFS population abundance by life stage and season is warranted, in particular investigations of the relationship between abundance and environmental factors within the Estuary.

According to Merz et al (2013), difficulty in assessing management effectiveness for anadromous fishes arises from several factors. First, anadromous life cycles are often complex and encompass both freshwater and marine ecosystems. Second, from a monitoring perspective, time series of counts at any one life stage reflect cumulative effects of freshwater, estuarine, and marine factors over the full life cycle, thereby complicating the ability to measure population responses to specific factors. Third, complex interactions of factors, which range from stream flow and temperature to large-scale and long-term shifts in marine conditions, occur. Because of these confounding factors, resource managers have not been successful in evaluating the effectiveness of managment actions that use the traditional method of quantifying abundance at single life stages in isolation. An alternative is to consider survival rates, life history variability, and the health (e.g., size, fecundity, disease) of a species that transitions between each life stage within the habitats that they occupy. Providing a spatial context for each life-stage of LFS, as we have done here, may facilitate our understanding of how Estuary habitats contribute to different life cycle stages and, thus, the effectiveness of management actions in improving population performance in the face of extrinsic constraints. Continued LFS investigations that focus on identifying, protecting, and enhancing aquatic habitats of the highest value contribute to Estuary science and management, and provide a basis for future conservation and restoration.

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Napa River Fisheries Monitoring Program
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2005

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Napa County Flood Control and Water Conservation District
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Final Report **January 2006**

Executive Summary

The Napa River/Napa Creek Flood Protection Project was designed by the Napa County Flood Control and Water Conservation District and the U.S. Army Corps of Engineers to provide flood protection and improve habitat in the vicinity of the City of Napa by reconnecting the Napa River to its floodplain, creating wetlands throughout the area, maintaining fish and wildlife habitats, and restoring the natural characteristics of the river. The Napa Project is being implemented along 11.1 km (6.9 miles) of the Napa River in Napa County, California. The Project features include dike removal, channel modifications to create floodplain and marsh plain terraces, levees and floodwalls, bridge relocations, pump stations, and maintenance roads/recreation trails for the reach of the river from Highway 29 to Trancas Street. The Fisheries Monitoring Program involves sampling the enhanced areas and the surrounding habitats to evaluate the use of the areas by various fish species. The purpose of the Fisheries Monitoring Program is to determine fish use of the restored and created habitats (open water, marsh plain, and floodplain) created by the Napa Project, with special emphasis on threatened and endangered species.

Fish were captured using beach seines, otter trawls, purse seines, and fyke nets. The otter trawl was fished actively in the open water and floodplain sites. The purse seine was fished actively in the open water, during high tide slack water. The beach seine was fished in the marsh plain and floodplain terraces at varying tidal heights. Fyke nets were used in small channels in the floodplain where fish were likely to be concentrated during a falling tide.

The Fisheries Monitoring Program has documented that restoration of the area is providing habitat for native and non-native species. In 2005, a total of 928 larval fish and 2,170 juvenile and adult fish were captured. The larval catch was dominated by shimofuri goby, and the juvenile and adult species were dominated by inland silverside, threadfin shad, striped bass, and Sacramento splittail. The sampling program to date (March 2001 to July 2002, January 2003 to July 2003, March 2004 to July 2004, March 2005 to July 2005) has documented use of the Napa Project area by 74,952 larval, juvenile, and adult fish of 37 species. The number of fish captured varied widely between sampling sites within the Napa Project area.

Species assemblages varied annually and seasonally. In 2001, inland silversides dominated the catch in recently created/restored areas. In 2002, over 3,000 young-of-the-year Pacific herring were captured in created/restored habitats. In July 2003, an increase of striped bass and threadfin shad dominated the catch in created/restored and non-restored sites. Comparatively, in June–July 2004 and May–June 2005, Sacramento splittail were the most abundant native fish captured in the same created/restored habitats. Results to date indicate that: 1) juvenile Sacramento splittail abundance is positively correlated with salinity in created/restored habitat; 2) juvenile Sacramento splittail were more abundant in shallow created/restored habitat than surrounding deep non-restored habitat; 3) juvenile Sacramento splittail were found to have a greater abundance in created marsh plain habitat than in restored SWOA floodplain habitat; 4) striped bass appear to have a seasonal distribution and abundance is positively correlated with salinity; 5) inter-annual variability was observed with inland silverside, threadfin shad, Pacific herring, and Sacramento splittail. Variability in species assemblages reflects changes in environmental conditions and possibly successional changes in created flood and marsh plain habitat. Results of the monitoring

program have identified species that benefit from newly restored and created habitat, documented seasonal trends in habitat use, and revealed correlations between environmental conditions and fish distribution and abundance. The results of this project will be useful in developing approaches to restore fish habitat within the Bay/Delta.

Napa River Fisheries Monitoring Program
Final Report
2005

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1 Introduction

1.1 Background

Restored SWOA Site 1A-6, April 2005.

The Napa River/Napa Creek Flood Protection Project ("Napa Project") was designed by the Napa County Flood Control and Water Conservation District and the U.S. Army Corps of Engineers (USACE) to provide flood protection for and improve habitat in the vicinity of the City of Napa by reconnecting the Napa River to its floodplain, creating wetlands throughout the area, maintaining fish and wildlife habitats, and restoring the natural characteristics of the river. The Project consists of five separate contracts developed as a cooperative effort between the City of Napa, Napa County, the USACE, Community Coalition, Federal and State resource agencies, and consultants. Construction of the Project is currently phased over seven years from 2000 through 2006.

The Napa River Fisheries Monitoring Program (FMP) was developed as a requirement of the 9 April 1999 U.S. Fish and Wildlife Service (USFWS) Biological Opinion for the Napa Project. The FMP is primarily designed to describe the presence of fish species in the area before and after construction of the Napa Project. Fish habitat restoration features of the flood protection project are being monitored to determine use of the area by various fish species. The latest work plan for the FMP was published in March 2003 (USACE 2003a). The FMP is coordinated with other government sponsored scientific studies in the Bay-Delta, and is Interagency Ecological Program Element 2005-105. Fish surveys began in July 2001 and have continued through July 2005.

1.2 Project Description

The Napa Project is being implemented along 11.1 km (6.9 miles) of the Napa River in Napa County, California (Figures 1-1 and 1-2). Project features include dike removal, channel modifications to create floodplain and marsh plain terraces, bridge relocations, and construction of levees and floodwalls, pump stations, maintenance roads, and recreation trails for the reach of the river from Highway 29 to Trancas Street.

The Napa Project also includes the Napa River Enhancement Plan for the South Wetlands Opportunity Area (SWOA). This enhancement plan calls for restoration of physical and biological processes in the Napa River estuary and the SWOA, extending along the west side of the river from Newport North Marina to the Highway 29 bridge, by creating 104 acres of emergent marsh, converting 262 acres of farmland to emergent marsh, and creating and enhancing 136 acres of seasonal wetlands (USACE 2001a). The enhancement plan includes lowering levees, breaching dikes, and constructing marsh plain and floodplain terraces. The SWOA is designed to provide flood relief for the town of Napa and surrounding areas, once the Napa River reaches 12,000 cfs (William Hall, USACE, pers. comm., 2005).

The FMP involves sampling of the enhanced areas and surrounding habitats to monitor the use of the areas by various fish species. Information gathered as part of the FMP will potentially influence future management decisions and restoration designs, and serve to validate environmentally fish-friendly designs in future flood control programs. Data collected as part of the FMP will also be used to guide the adaptive management decisions described in the Mitigation Monitoring Program for the Napa Project (Jones and Stokes 2001).

1.3 Construction Project Status

The status of construction contracts for the Project is presented in Table 1-1.

Table 1-1. USACE Construction Project Status.[1]

Construction Project	Description	Status
Contract 1A	Terrace excavation and construction of vineyard dike	Completed Fall 2000
Contract 1A Plantings	Revegetation Contract	Completed Fall 2003
Contract 2	Napa Valley Wine Train Phase 1 Relocation	Completed January 2003
Petroleum Contaminated Soil Remediation	Creation of marsh plain terrace and floodplain terrace habitat	Completed December 2003
Contract 1B	Marsh plain and floodplain excavation	Completed April 2004
Contract 1B Plantings	Revegetation Contract	Completed Spring 2005
Remediation Area Plantings	Revegetation Contract	Completed Spring 2005
Sixth to Third Excavation	Marsh plain excavation	Completed Fall 2004
Napa Sanitation District Excavation	Marsh plain and floodplain excavation	Complete in Summer 2005
Hatt to First Reach	Marsh excavation and flood wall construction	Complete in Spring 2007
Napa Valley Railroad Phase 2 Relocation	Relocate 2,100 ft	Complete in 2008
Oxbow Bypass Excavation	Excavate dry bypass at oxbow	Complete in 2008

[1] Mike Dietl, USACE, pers. comm., 2002, Larry Dacus, USACE, pers. comm., 2004, Will Hall, USACE, pers. comm., 2003 and 2005.

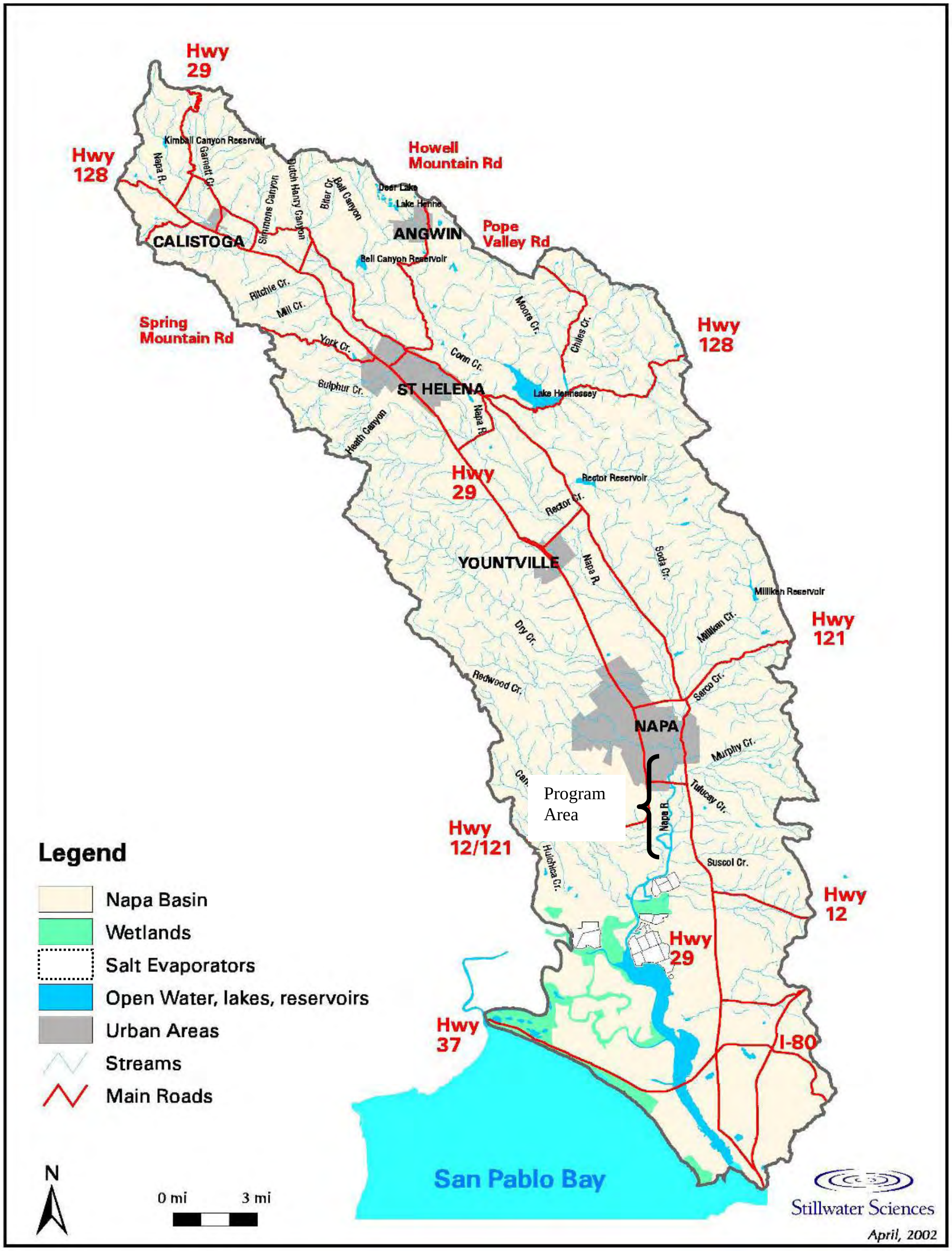


Figure 1-1. Map of the Napa River Fisheries Monitoring Program area.

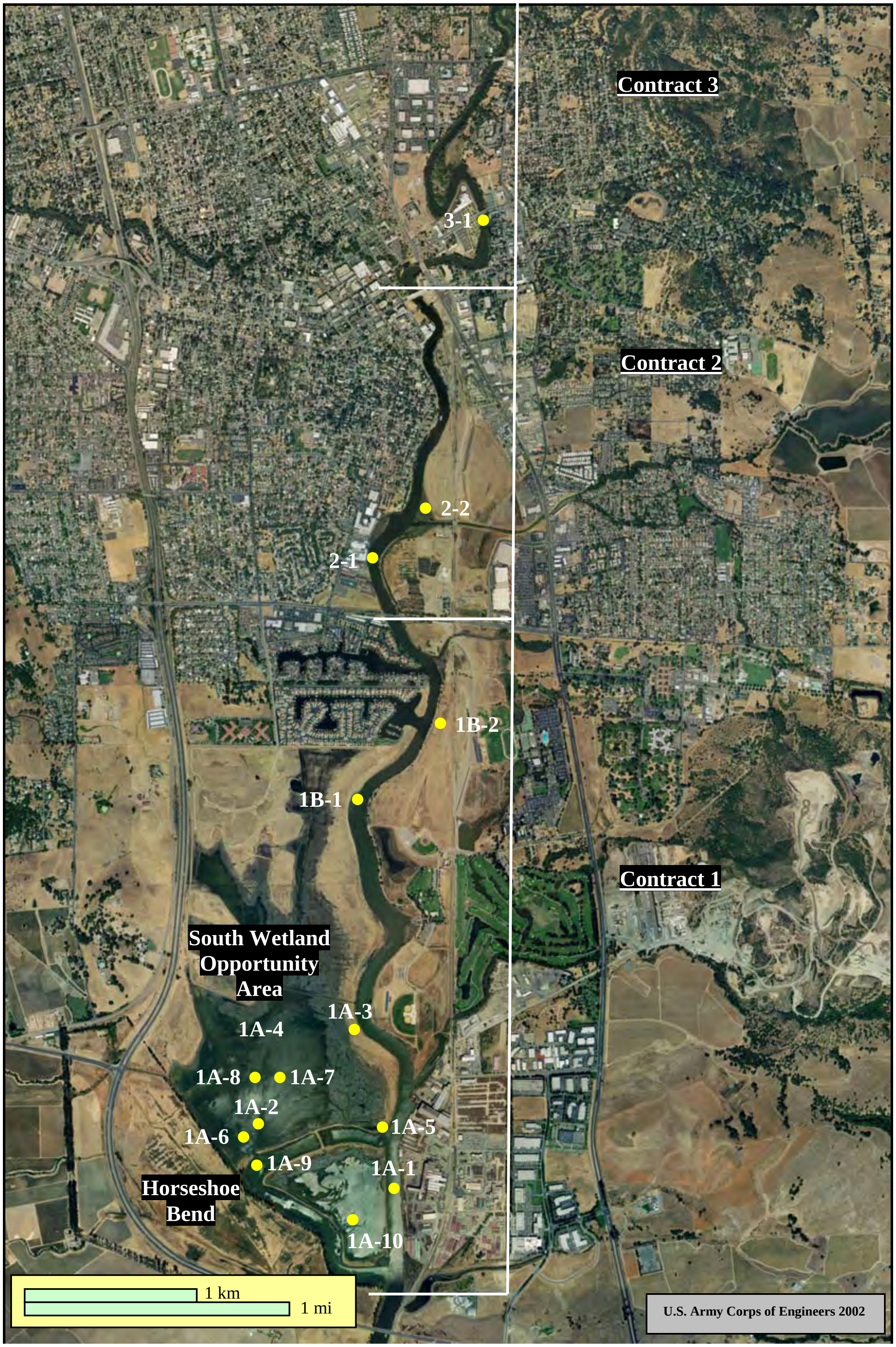


Figure 1-2. Aerial photograph of the Napa River Fisheries Monitoring Program area.

1.4 Fisheries Monitoring Objectives and Status

The purpose of the FMP is to determine fish use of the restored and created habitats (open water, marsh plain, and floodplain) created by the Napa Project, with special emphasis on threatened and endangered species. Sampling efforts in 2005 consisted of monthly sampling between March and July, plus semi-monthly sampling in March and May.

Although this annual report is for 2005, parts of this report also include data from 2001, 2002, 2003, and 2004 (particularly Appendices A and B). Tables and figures are labeled according to the year data were collected.

The FMP has the following objectives:

1) Document presence and relative abundance of fish species (particularly delta smelt and Sacramento splittail) utilizing restored and created habitats.

2) Document life stages and seasonality of fish species (particularly delta smelt and Sacramento splittail) in restored and created habitats.

3) Determine if correlations exist between collected fish species and under specific environmental conditions at each sampling site.

In order to meet these objectives, the following hypotheses were developed as part of the monitoring program:

- Fish, in particular delta smelt and Sacramento splittail, will use habitat created or restored by the Napa Project.
- Certain life stages of fish species, in particular delta smelt and Sacramento splittail, will use specific habitat types in the Napa Project area during specific seasons and under specific environmental conditions.

Delta smelt captured in the restored SWOA, 2002

Fish surveys have documented that the restoration of the SWOA and marsh plain terraces is providing habitat for native and non-native species. In 2005, a total of 3,098 fish were captured, including 2,170 juvenile and adult fish from 37 species, and incidental capture of 928 larval fish from 6 species. To date (July 2001–July 2002, January 2003–July 2003, March 2004–July 2004, and March 2005–July 2005), a total of 14,961 juvenile and adult fish have been captured, representing 37 species. Native and non-native species captured in 2005 include the following:

Native species:
- chum salmon
- long-jawed mudsucker
- Pacific herring
- prickly sculpin
- Sacramento splittail
- Sacramento sucker
- staghorn sculpin
- starry flounder
- steelhead
- threespine stickleback
- tule perch

Non-native species:
- American shad
- bluegill
- common carp
- inland silverside
- rainwater killifish
- yellowfin goby
- shimofuri goby
- striped bass
- threadfin shad
- white crappie

Subsequent sections of this document present the methods and results of the FMP, and address the objectives and hypotheses stated above. Background information, data, and reports associated with the FMP (including this report) are available online at *http://www.napariverfishmonitoring.org*.

Results of the FMP have been presented at the 2005 State of the San Francisco Estuary Conference (Kramer *et al*. 2005), 2005 California-Nevada Chapter American Fisheries Society Annual Conference (Dusek *et al*. 2005), and the 2003 and 2005 CALFED Science Conference Annual Meetings (Dietl *et al*. 2003, 2005).

Long-jawed mudsucker captured at restored Site 1B-2, May 2005.

2 Methods

2.1 Site Selection

On 8 June 2001, Stillwater staff and USACE personnel established 13 fish monitoring sites along 11.1 km (6.9 mi) of the Napa River and SWOA within the Napa Project area (Figure 1-2, Table 2-1) (USACE 2001b). Individual sites were typically marked by 1.3–2.4 m (6–8 ft) metal posts driven into the substrate, spray-painted orange, and flagged with green tape. Chaudhary and Associates surveyed the selected sample sites (USACE 2001b) to a tolerance of 0.3 m (0.9 ft) for latitude and longitude, and 0.15 m (0.5 ft) for elevation. The 13 sites represented three habitat types that may attract breeding and rearing delta smelt and Sacramento splittail: marsh plain terrace (created), floodplain terrace (restored), and open water (non-restored) habitat. Seven sites were located in the SWOA, including two sites in the Horseshoe Bend channel and five sites north of the levee breach (Figure 1-2, Table 2-1). Three marsh plain sites were located east of the SWOA area and along the mainstem of the Napa River (Figure 1-2, Table 2-1). Five open water sites were located throughout the mainstem of the Napa River, from just east of the SWOA in the main channel continuing throughout the 11.1 km (6.9 mi) Project area (Figure 1-2, Table 2-1). Three sites were subject to minor relocations from 2001 to 2002 (Table 2-1). One site was eliminated because no fish were captured (Site 1A-5). In 2003, 2004, and 2005, two sites were not sampled due to lack of funding (Sites 1A-8 and 1A-9), and one new site was discontinued to concentrate sampling effort on sites with historical data (Site 2-2).

Table 2-1. Sampling Site Locations for the Napa River Monitoring Fisheries Program.

Site No.	Latitude			Longitude			Elevation (mean sea level)
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	(feet)
1A-1	38	15	17.70	122	17	0.30	N/A
1A-2[a]	38	14	54.57	122	17	16.94	4.0
1A-3	38	16	2.07	122	17	11.43	0.6
1A-4[b]	38	16	1.38	122	17	15.73	5.7
1A-6[a]	38	15	13.49	122	17	37.57	-3.2
1A-7	38	15	21.59	122	17	34.58	-0.5
1A-8[c]	38	15	21.34	122	17	38.15	-1.1
1A-9[c]	38	15	11.12	122	17	38.16	4.3
1A-10[a]	38	14	57.73	122	17	16.78	-3.3
1B-1	38	16	23.10	122	17	4.70	N/A
1B-2	38	16	38.40	122	16	50.30	N/A
2-2	38	17	24.70	122	16	53.90	N/A
2-1	38	17	10.10	122	17	0.20	N/A
3-1	38	18	8.71	122	16	43.88	26.5
Standpipe[b]	38	16	4.84	122	17	26.26	2.6

[a] Positions approximate due to minor relocations in 2002.

[b] Standpipe and a t-bar post at Site 1A-4 were used for obtaining position bearings during roving beach seines in the SWOA if a GPS signal could not be recorded.

[c] Positions not sampled in 2005.

2.2 Site Descriptions

Sampling locations are documented in Figure 1-2, with brief descriptions of each site provided below.

Site 1A-1 was sampled with an otter trawl. The site position was previously established by CDFG for the 20 mm tow-net surveys in 2001. This site was located by the SWOA in the main Napa River channel, in close proximity to the peninsula formed by Horseshoe Bend.

Site 1A-2 was sampled with an otter trawl. It was originally located in the upper reaches of the main drainage channel in Horseshoe Bend (west of current Site 1A-10). However, due to excessive and repeated clogging of the otter trawl by debris (e.g., automobile tires), the site was relocated to the main channel that flows north-south through the SWOA.

Site 1A-3 was sampled with a beach seine and was located on the west bank of the main channel of the Napa River, just upstream of the JFK Park boat ramp. The site was located on bare earth or mud where a levee was removed by the USACE as part of the Napa Project. The site was inundated during high tides. Site 1A-3 was originally sampled with a fyke net, but it was found to be more effectively sampled with a beach seine.



Creation of marsh plain terrace Site 1A-3: Pre-restoration condition (left), post- construction habitat (middle), and sampling habitat at high tide (right).

Site 1A-4 was an area at the north end of the SWOA sampled by beach seine. The beach seine was used to sample various locations in the marsh during flood, high, and ebb tides.

Site 1A-5 was sampled by fyke net and was initially sampled through November 2001. However, since the fyke net did not capture any fish, sampling effort was redirected to other sites.

Site 1A-6 was sampled by fyke net. The location of this site was moved out of the main SWOA channel due to human safety and fish injury concerns: the location in the main channel exposed the fyke net to high water velocities making placement and removal of the fyke net dangerous and increasing the potential for injury and mortality to the fish captured. The net at this site was originally positioned to sample fish that concentrated in the tidal channel during a receding tide. In 2001, the site was moved to the east side of the terrace where water velocities were lower. In 2002, the site was relocated about 7 m (23 ft) west from its original location, across the main channel, in a small channel that drains the southwest portion of the SWOA.

Site 1A-7 was sampled by fyke net. This site was located in a tidal channel that drains from the eastern side of the SWOA marsh into the main marsh channel, which drains into Horseshoe Bend. This site was established to sample fish that concentrate in the tidal channel during a receding tide.

Site 1A-8 was also sampled by fyke net. The site was located in a tidal channel that drains from the western side of the SWOA marsh and captured fish that concentrated in the tidal channel during a receding tide. This site was not sampled in 2004 and 2005 due to budget constraints.



Pre-restoration condition in the SWOA in June 2001 (left) and post-construction habitat (middle and right).

Site 1A-9 was sampled with a purse seine and was located at the levee breach where the main SWOA marsh channel enters Horseshoe Bend. This site was established to sample fish distributed in mid-water depths at the levee breach. This site was not sampled in 2004 and 2005 due to budget constraints.

Site 1A-10 was sampled with a fyke net and was located slightly upstream of the peninsula levee breach (on Horseshoe Bend). This site was established to sample fish concentrated in the channel during a receding tide. The location of this site was moved out of the channel due to human safety and fish injury concerns: the location in the channel exposed the fyke net to high water velocities making placement and removal of the fyke net dangerous and increasing the potential for injury and mortality to the fish captured. In 2002, the site was moved about 9.5 m (31 ft) northwest from its initial location to an outflow channel that allowed safer boat and wading access.

Non-restored Site 1B-1, July 2002

Site 1B-1 was in open water and was sampled by otter trawl. It was located in the main Napa River channel, 1 km (0.6 mi) upstream of the JFK Park boat ramp.

Site 1B-2 was sampled with a beach seine and was located on the east bank of the main channel of the Napa River, just across from River Park Marina. The site was located where a levee was removed by the USACE as part of the Napa Project. The site was only inundated during flooding and high tides.

Site 2-1 was in open water and was sampled by otter trawl. It was located in the main Napa River channel, at Jacks Bend (Tulocay Creek confluence).

Site 2-2 was sampled with a beach seine and was located on the east bank of the main channel of the Napa River, just upstream of Tulocay Creek. The site was located where a levee was removed by the USACE as part of the Napa Project. The site was only inundated during flooding and high tides.

Site 3-1 was in open water and was sampled by purse seine. This site was located in the main Napa River channel, just downstream of the First Street Bridge, and provided a more upstream mid-water habitat site.

2.3 Sampling Schedule

Selected sites were used to sample on a monthly or semi-monthly schedule (Table 2-2).

Table 2-2. Napa River Fisheries Monitoring Program: Monthly Sampling Schedule in 2005.*

Site	Classification	Description	March		April	May		June	July
			9–10	23–24	20–21	5–6	18–19	29–30	28–29
1A-1	Open water	Open water (river)	OT	OT	OT	OT	OT	OT	OT
1A-2	SWOA	SWOA slough	OT	OT	OT	OT	OT	OT	OT
1A-3	Marsh plain	Marsh plain terrace	BS	BS	BS	BS	BS	BS	BS
1A-4	SWOA	Floodplain terrace	BS	BS	BS	BS	BS	BS	BS
1B-2	Marsh plain	Marsh plain terrace	BS	BS	BS	BS	BS	BS	BS
2-2	Marsh plain	Marsh plain terrace	BS	BS	BS	BS	BS	BS	BS
1A-6	SWOA	SWOA marsh	FN	FN	FN	FN	FN	FN	FN
1A-7	SWOA	SWOA marsh	FN	FN	FN	FN	FN	FN	FN
1A-10	SWOA	SWOA HB marsh	FN	FN	FN	FN	FN	FN	FN
1B-1	Open water	Open water (river)	OT	OT	OT	OT	OT	OT	OT
2-1	Open water	Open water (river)	OT	OT	OT	OT	OT	OT	OT
3-1	Open water	Open water (river)	PS	PS	PS	PS	PS	PS	PS

*FN = fyke net; PS = purse seine; OT= otter trawl; BS = beach seine.

2.4 Sampling Methods

Various gear types tested in 2001 and subsequent adjustments are presented in detail in the 2001 Napa River Fisheries Monitoring Program Annual Report (USACE 2002). Except where noted, sampling during the March 2005 through July 2005 periods used the same gear types and methods.

Four gear types were used to sample fish in the Project area, using a 6.4 m (21 ft) aluminum workboat. Fyke nets were used in small channels in the marsh plain and floodplain terraces where fish were likely to be concentrated during a falling tide. The purse seine was fished in the open water sites, during high tide slack water. The otter trawl was fished in the open water sites at varying tidal heights. The beach seine was fished in the marsh plain and floodplain terraces at varying high tidal heights and during flooding periods. Gear specifications and replicate numbers are presented in Table 2-3.

Table 2-3. Napa River Fisheries Monitoring Program: Gear Specifications and Level of Effort in 2005.

Gear/ Sampling Technique	Dimensions	Mesh Size	Site Locations	Sampling Duration	Number of Samples per Sampling Event
Fyke Nets	Opening: 0.9-1.2 m Length: 6.1-9.2 m Leads: 3.1 m	0.64 cm	SWOA Slough (1A-6), SWOA Marsh (1A-7), SWOA-Horseshoe Bend Marsh (1A-10)	4-6 hours per set	1 set
Otter Trawl	Opening: 1 x 2.5 m Length: 5.3 m	Variable: 0.64 cm–3.8 cm	Open Water-Horseshoe Bend (1A-2), Open Water (1A-1), Open Water (2-1), Open Water (1B-1)	10-15 minutes per tow, at 1-2 knots	2-3 tows
Purse Seine	Length: 30.5 m Depth: 1.8 m	0.64 cm	Open Water (3-1)	20-30 minutes per set	2-3 sets
Beach Seine	Length: 30.5 m (2001–2002) and 15.2 m (2003–2005) Depth: 1.2 m plus bag	0.64 cm	Floodplain Terrace (1A-4), Marsh Plain Terrace (1A-3), Marsh Plain Terrace (2-2), Marsh Plain Terrace (1B-2)	20 minutes per haul	2-3 hauls

2.4.1 Fyke nets

Fyke net

Fyke nets were deployed to capture fish in shallow marsh areas with moderate to swift current. The fyke nets were approximately 3.6 m (12 ft) long with 0.64 cm (¼ in) mesh. Each net consisted of seven 0.91 m (3 ft) diameter hoops with two 3 m (10 ft) leads. Fyke nets were secured in the current by t-posts that had been driven into the substrate. Four pieces of PVC pipe were attached to the entrance of the net and each wing, and slid over the t-posts. The pipe facilitated deployment and retrieval, and a secure fit of the nets to the t-posts. Fyke nets were deployed during daytime high tides and were fished for approximately four to six hours during the receding tide. During the receding tide, the fyke net wings diverted the fish into the traps. The field crew retrieved the nets during the ebbing tide, and collected all fish that were captured. All fyke nets were removed from the water after each sample was collected. Catch per unit effort (CPUE) was calculated by dividing the number of fish of each species by the time the fyke net was fished (beginning at the time of slack tide).

2.4.2 Otter trawl

Otter trawl

An otter trawl was used to sample benthic and mid-water column fish. The body and the tail, or "cod" end of the net was 0.64 cm (¼ in) mesh. The mouth opening was 1 m (3.3 ft) x 2.5 m (8.2 ft) and the length was approximately 5.3 m (17.4 ft). The otter trawl was towed from the stern of the boat for approximately 10 minutes to minimize stress to captured fish. The otter trawl was fished once or twice a month during daylight hours, around high tide slack water. The water volume sampled by the trawl was calculated using a General Oceanics flow meter that was towed from the side of the boat. The flow meter was calibrated over a measured distance prior to sampling. Trawl volume was calculated by multiplying the amount of water sampled (represented by flow meter readings) by the known area of the net opening. CPUE was calculated by dividing number of fish of each species by the volume of water sampled.

2.4.3 Purse seine

A purse seine was used to sample fish concentrated in the mid-water zone. The seine was 30.4 m (100 ft) long by 2.5 m (8 ft) deep with 0.64 cm (¼ in) mesh. The top of the net was connected to floats which supported the net in open water. The net was deployed off the boat in a circular pattern. Once the circle was completed, the purse line along the bottom of the net was pulled tight to seal the opening, trapping the fish. The volume of water sampled was calculated by estimating the length and width, or the diameter, of the enclosure formed by the deployed seine. CPUE was calculated by dividing the number of fish of each species by the water volume.

Purse seine

2.4.4 Beach seines

Two beach seines were used alternately to target fish in shallow water habitats with low to moderate water velocities. The beach seines sampled the entire water column. The nets were supported at the surface by floats and weighted with a lead line to provide contact with the bottom. The first beach seine, measured 30.5 m (100 ft) long by 1.8 m (6 ft) high was used in 2001 and 2002. The second beach seine, measured 15.3 m (50 ft) long by 1.8 m (6 ft) high was used between 2003 and 2005. Both seines had 0.64 cm (¼ in) mesh with a 1.8 m^2 (6 ft^2) bag. One sampling method involved deploying the beach seine from the boat, which required one end of the seine to be secured onto the bank and one end secured to the boat. The boat was backed away from the shore, deploying the net, and then was driven back to the shore downstream or upstream of where the seine was secured on the bank. The seine was then pulled onto the shore by hand. Alternatively, in shallow water, the beach seine was stretched out between two people and dragged through the water toward shore or back to the boat where it was hauled out of the water. Beach seining was conducted during the day, near slack water at high tide each month. The volume of water sampled was estimated by multiplying the seine width by water depth and the distance covered. CPUE was calculated by dividing the number of fish of each species by the calculated volume of water sampled.

Beach seine

2.4.5 Fish processing

After retrieving the sampling gear, fish were placed into buckets with water. Fish were kept in water during processing, and gloves used where necessary and practical to minimize injury to fish. All fish specimens were collected, processed, and returned to the water as soon as possible.

The following data were recorded for fish collected at each sampling site:

- Identification to species level;
- Fork length (FL) (mm). If large numbers of a non-listed fish species were captured (e.g., inland silversides), then the total number of fish was counted and a representative sample (n=50) was measured. Starting July 2003, standard length (SL)(mm) and total length (TL) (mm) of splittail was measured to facilitate age/length correlations. For the 2001-2003 Sacramento splittail data analysis, fork length was converted to standard length (FL = 0.8722 x SL – 0.2657) (Randy Baxter pers. comm., California Department of Fish and Game, 2003). Splittail were classified as juveniles when less than 170 mm SL and adults when greater than 170 mm SL (Moyle *et al.* 2004).
- Weight (g) was measured for all listed species and splittail;
- Reproductive state or spawning stage was verified for splittail by applying mild pressure to the abdomen to determine if milt or eggs could be expressed;
- Noticeable lesions were recorded for listed species and splittail;
- Photos were taken of representative fish species.

2.4.6 Larval fish processing

The 2005 surveys incidentally captured larval fish in the adult and juvenile sampling gear (fyke nets, beach seines, and otter trawls). Larval fish captured in 2005 were processed using the larval fish processing protocol described in USACE 2002. Larval fish species were identified in the laboratory. For samples containing more than one hundred fish of the same species, the first one hundred were measured and lengths were estimated for the remaining fish. Quality Assurance and Quality Control (QA/QC) was performed by a larval fish specialist to insure correct identification of larval fish.

2.4.7 Environmental conditions

Environmental conditions were measured while sampling at each site on each sampling day. The Napa River discharge was determined from the Napa River gaging station. The Napa River gaging station near Napa (#11458000) is operated by U.S. Geological Survey and Department of Water Resources. The gaging station is located 9.6 km (6.0 mi) upstream of the Project area (38^{o} 36’ 70”N, 122^{o}30’00”W) and did not include inflow from Napa Creek and Soda Creek, as their confluence with the Napa River is below the gaging station.

Digital photographs were taken at each site to document vegetation conditions, site conditions, and examples of captured fishes. These digital photographs were catalogued along with the associated site identification. The following data were collected at each site and input into the FMP database:

- Dissolved oxygen (mg/l), water temperature (^{o}C), and salinity (ppt) were measured at the surface and bottom at each site with a YSI Model 85 meter.
- Turbidity (mm) was measured using a Secchi disk. The disk was lowered into the water column on a cable, and the greatest depth at which the disk could be observed was recorded in cm.
- Tidal elevation (ft) was noted daily from a Napa River gage near the Horseshoe Bend confluence. The tide elevation during each sampling event was calculated with the use of a Nautical Software tidal chart for the Napa River.
- Water depth (ft) was measured via marks on a stadia rod or with a depth sounder.
- Photos were taken with a Cannon A40 digital camera (resolution 1024x768).

2.5 Quality Control Procedures

The methodology and standard operating procedures implemented for quality control (Q/C) are described in the Final Workplan and QA/QC Plan for Implementation of the Year 2001 Napa River Fisheries Monitoring Program (USACE 2001a) and are summarized below.

2.5.1 Preparation of equipment

All equipment was prepared and calibrated prior to each sampling trip. The following list itemizes equipment preparation procedures:

- YSI 85 meter (DO, Salinity, Temperature, Conductivity): calibrate to manufacturer's specifications.
- General Oceanics flow meter: initially calibrate the number of revolutions with the distance traveled through the water. Recheck calibration prior to each sampling trip.
- The "calibration checklist" on the data sheets was used to verify completed calibration procedures for all equipment, and completion was noted on the data sheets for each field effort.

2.5.2 Sample replications

Replicate samples of two or three tows, or sets, were performed at sites where an otter trawl, purse seine, or beach seine was used.

There were no replicate samples taken at the fyke net sites. Individual fyke nets were set monthly or semi-monthly at each site, and generally "fished" from high slack tide until their retrieval near low tide.

2.5.3 Sample preservation, transportation, storage and disposal

Specimens used to confirm positive fish species identification in larval and adult samples collected by the FMP Implementation Team were preserved in 10 percent formalin and placed in glass or plastic specimen jars for storage. Jars were labeled with date, time, location, and the sample collector's name. Fish collected for fish identification are currently being stored at Stillwater Sciences in Arcata.

2.5.4 Sample and data collection

Field data were collected on standard forms to minimize the potential for missing values. The Field Leader, or other crew members that did not record the data, reviewed the datasheets on a daily basis for the following:

- Completion of all data fields
- Reasonableness of measurements
- Legibility of recorded data

The reviewer initialed each data sheet as having been reviewed for accuracy and completeness before leaving the site on each sampling date.

2.5.5 Data summary and processing

Following field data checking, additional Q/C measures were implemented during data entry and data summary. During data entry into the relational database, the database software was able to prevent or detect many types of errors with the following methods:

Mandatory Fields. Although not all fields must be entered for every record, there are many mandatory fields, such as sampling-site identification number and date.

Data Format Checks. The data entry form prevented the wrong type of data from being entered into a field. For example, text could not be entered into numeric fields, and numeric data must be entered with the correct decimal placement.

Lookup Tables. Many data elements had unique values that must be used, such as fish sample method and sampling site identification number. Rather than enter values for these fields and risk making a typographical error, lookup tables were used with data entry drop-down menu lists, so that only a listed, valid value could be selected.

Numeric Range Tests. For numeric data elements, such as fish counts, the value entered was tested against preset minimum and maximum values, to ensure that the data entered was within the valid range.

Incomplete or Illegible Data. If the field data collection forms had illegible or missing mandatory data, the data was corrected and a member of the QA/QC team revised the database with the correct information.

Data Entry Report and Field Form Comparison. At the completion of each data entry session, the data entry technician printed out a report of the data entered. This printout was compared to the field data entry forms for accuracy.

3 Results

3.1 Fish Relative Abundance and Distribution

In 2005, 2,170 juvenile and adult fish were sampled, representing 12 native and 10 non-native species (Table 3-1 and Table B-1, Appendix B). In addition, 928 larval fish were captured (Table 3-2), representing 2 native and 4 non-native species (Table 3-1 and Table B-2). The most abundant juvenile or adult species captured in 2005 was inland silverside (n=860, 39 percent), followed by threadfin shad (n=338, 16 percent), striped bass (n=325, 15 percent), and Sacramento splittail (n=305, 14 percent) (Table B-1, Figure 3-1). The remaining 17 species comprised 16 percent of the 2005 catch.

All gear types captured fish in 2005 (Figure A-1 [Appendix A]): the beach seine captured the greatest percentage of fish (73 percent), followed by otter trawl (18 percent), fyke net (5 percent), and purse seine (4 percent). The dominant species captured by each gear type was striped bass in the otter trawl (44 percent), inland silverside in the beach seine (51 percent), Sacramento splittail in the fyke nets (40 percent), and threadfin shad in the purse seine (64 percent) (Figure A-2).

Differences in fish species composition were observed in different habitat types from March to July 2005 (Figures A-3 through A-5). Marsh plain habitats were dominated by inland silverside (53 percent) followed by Sacramento splittail (14 percent), threadfin shad (10 percent), and striped bass (10 percent). In open water habitats, threadfin shad was the most abundant (41 percent) followed by striped bass (34 percent) and tule perch (8 percent). SWOA habitats were dominated by Sacramento splittail (27 percent), followed by striped bass (13 percent) and threadfin shad (9 percent).

Larval fish were incidentally captured in 2005 with fyke nets, beach seines, and otter trawls while sampling for juvenile and adult fish in the SWOA, marsh plain, and open water habitats. The dominant larval species was shimofuri goby (84 percent), followed by *Tridentiger* or other unidentified goby species (6 percent), and striped bass (3 percent) (Figure A-6, Tables 3-1 and 3-2). Larval longfin smelt and yellowfin goby were most abundant in May; larval Pacific herring, striped bass, *Tridentiger* spp., and threadfin shad were most abundant in June, and shimofuri goby was most abundant in July (Table 3-2).

Non-native species were always a higher percentage of the catch than native species in every month surveyed in 2005 (Figure 3-2). Native species abundance was highest in May, June, and July (Figure 3-2).

Restored Site 1A-10, May 2005.

As in previous years of sampling, there was a notable difference between the distribution of native and non-native species by the habitat types in the Napa River Project area in 2005. Non-native species represented 85 percent of the catch in the open water habitat, 78 percent in the marsh plain habitat, and 65 percent in the SWOA habitat (Figure 3-3). In the SWOA and open water habitats the proportion of native and non-native species was similar (9 native, 8 non-native species), compared to the marsh plain where a lower proportion of native species was observed (7 native, 8 non-native species) (Figure 3-4).

3.2 Fish Relative Abundance and Distribution

In 2005, physical conditions in the project area varied similarly to surveys from previous years. During winter, physical conditions were characterized by low water temperatures, very low salinities, high dissolved oxygen, and high freshwater inflow (Figures A-7 through A-10). In the spring, salinity and water temperature began to increase, while dissolved oxygen decreased. Summer conditions exhibited moderately high temperatures, low dissolved oxygen, and higher salinity levels. These conditions are associated with changes in freshwater inflows from the Napa River that are typically highest in December and decrease in the spring. With low freshwater inflow in the summer and fall months, salinities and temperatures increased, and dissolved oxygen decreased. Environmental conditions at each sample site between 2001 and 2005 are provided in Table C-1 (Appendix C).

Monthly mean water temperature during the 2005 field effort ranged from a low of 13.7^{o}C (56.7^{o}F) in March and steadily increased into early summer to a high of 24.2^{o}C (75.6^{o}F) in July. Salinity ranged from a low of 0.1 ppt in March to a high of 9.5 ppt in July, and dissolved oxygen decreased from a high of 10.8 mg/l in April to a low of 5.1 mg/l in July. Average monthly Secchi readings ranged from a relatively high visibility reading of 0.7 m (2.3 ft) in April to a low of 0.3 m (0.9 ft) in June. However, unlike seasonal trends observed in temperature, salinity, and dissolved oxygen, there was no apparent trend between water clarity and season. Average daily mean flows measured at the USGS Napa River gaging station near Napa (# 11458000) decreased from a high of 700 cfs in March to a low of 13 cfs in July 2005 (Table 3-3).

Table 3-1. Napa River Fisheries Monitoring Program: Fish Species Captured in 2001–2005.

Common Name	**Scientific Name**	**Native or Non-native**	**Mar–Dec 2001**	**Feb–Jul 2002**	**Jan–Jul 2003**	**Mar–Jul 2004**	**Mar–Jul 2005**
Atherinopsidae, silverside family							
Inland silverside	*Menidia beryllina*	Non-native	■	■	■	■	■
Catostomidae, sucker family							
Sacramento sucker	*Catostomus occidentalis*	Native	■		■	■	■
Centrarchidae, sunfish family							
Black crappie	*Pomoxis nigromaculatus*	Non-native		■	■	■	
Bluegill	*Lepomis macrochirus*	Non-native			■		■
Largemouth bass	*Micropterus salmoides*	Non-native			■	■	
White crappie	*Pomoxis annularis*	Non-native					■
Clupeidae, herring family							
American shad	*Alosa sapidissima*	Non-native	■	■	■	■	■
Northern anchovy	*Engraulis mordax*	Native	■	■			
Pacific herring	*Clupea pallasii*	Native	■	■	■	■	■
Threadfin shad	*Dorosoma petenense*	Non-native	■	■	■	■	■
Cottidae, sculpin family							
Prickly sculpin	*Cottus asper*	Native	■	■	■	■	■
Staghorn sculpin	*Leptocottus armatus*	Native	■	■	■	■	■
Cyprinidae, minnow family							
Common carp	*Cyprinus carpio*	Non-native	■	■	■	■	■
Golden shiner	*Notemigonus crysoleucas*	Non-native		■		■	
Sacramento splittail [CSC]	*Pogonichthys macrolepidotus*	Native	■	■	■	■	■
Sacramento pikeminnow	*Ptychocheilus grandis*	Native				■	
Embiotocidae, surfperch family							
Tule perch	*Hysterocarpus traski*	Native	■	■	■	■	■
Fundulidae, killifish family							
Rainwater killifish	*Lucania parva*	Non-native			■	■	■
Gasterosteidae, stickleback family							
Threespine stickleback	*Gasterosteus aculeatus*	Native	■	■	■	■	■
Gobiidae, goby family							
Arrow goby	*Clevelandia ios*	Native	■				
Bay goby	*Lepidogobius lepidus*	Native	■				
Long-jawed mudsucker	*Gillichthys mirabili*	Native	■	■			■
Shimofuri goby	*Tridentiger bifasciatus*	Non-native	■	■	■	■	■
Yellowfin goby	*Acanthogobius flavimanus*	Non-native	■	■	■	■	■
Ictaluridae, catfish family							
Channel catfish	*Ictalurus punctatus*	Non-native		■			
White catfish	*Ameiurus catus*	Non-native			■		
Moronidae, temperate bass family							
Striped bass	*Morone saxatilis*	Non-native	■	■	■	■	■
Osmeridae, smelt family							
Delta smelt [FT, CT]	*Hypomesus transpacificus*	Native	■	■			
Jack smelt	*Atherinopsis californiensis*	Native	■				
Longfin smelt [CSC]	*Spirinchus thaleichthys*	Native	■	■	■	■	■
Wakasagi	*Hypomesus nipponensis*	Non-native	■	■			

Table 3-1 (continued). Napa River Fisheries Monitoring Program: Fish Species Captured in 2001–2005.

Common Name	Scientific Name	Native or Non-native	Mar–Dec 2001	Feb–Jul 2002	Jan–Jul 2003	Mar–Jul 2004	Mar–Jul 2005
Pleuronectidae, flounder family							
Speckled sanddab	*Citharichthys stigmaeus*	Native					
Starry flounder	*Platichthys stellatus*	Native					
Poeciliidae, livebearer family							
Western mosquitofish	*Gambusia affinis*	Non-native					
Salmonidae, salmon and trout family							
Chinook salmon	*Oncorhynchus tshawytscha*	Native					
Chum salmon	*Oncorhynchus keta*	Native					
Steelhead [FT]	*Oncorhynchus mykiss*	Native					

FT = Listed as threatened under ESA

CT = Listed as California Threatened

CSC = Listed as California Species of Concern

Table 3-2. Larval Fish Captured in the Napa River Project Area in 2005.

Location Code / Gear Type / Replicate Number	Longfin smelt	Pacific herring	Shimofuri goby	Yellowfin goby	Striped bass	Threadfin shad	*Tridentiger* spp.	Unidentified (damaged)	Total
Date: 20 April									
1A-2 Otter Trawl 2 of 2	0	0	2	0	0	0	0	0	2
1A-6 Fyke Net	1	0	1	0	0	0	0	0	2
April Subtotal	1	0	3	0	0	0	0	0	4
Date: 5 May									
1A-6 Fyke	0	1	0	0	0	0	0	0	1
1A-2 Otter Trawl 1 of 2	0	0	0	2	0	0	0	0	2
1B-1 Beach Seine 1 of 2	0	0	1	0	0	0	0	0	1
Date: 18 May									
1A-1 Otter Trawl 1 of 2	1	0	0	0	0	0	0	0	1
1A-2 Otter Trawl 1 of 2	1	0	0	1	0	0	0	0	2
1A-2 Otter Trawl 2 of 2	3	0	1	2	0	0	0	0	6
1B-1 Beach Seine 2 of 2	0	0	1	0	0	0	0	0	1
1A-7 Fyke Net	0	0	1	0	0	0	0	0	1
May Subtotal	5	1	4	5	0	0	0	0	15
Date: 29 June									
1A-1 Otter Trawl 1 of 2	0	0	41	0	2	0	0	0	43
2-1 Otter Trawl 2 of 2	0	5	0	0	4	1	0	0	10

Table 3-2 (continued). Larval Fish Captured in the Napa River Project Area in 2005.

Location Code / Gear Type / Replicate Number	**Longfin smelt**	**Pacific herring**	**Shimofuri goby**	**Yellowfin goby**	**Striped bass**	**Threadfin shad**	***Tridentiger* spp.**	**Unidentified (damaged)**	**Total**
Date: 30 June									
1A-3 Beach Seine 1 of 3	0	0	0	0	0	0	0	1	1
1A-3 Beach Seine 3 of 3	0	3	2	0	0	0	0	0	5
1B-2 Beach Seine 1 of 2	0	1	0	0	0	1	0	0	2
1B-1 Otter Trawl 1 of 2	0	0	89	0	1	0	0	5	95
1B-1 Otter Trawl 2 of 2	0	1	275	1	9	0	40	7	333
2-1 Otter Trawl 1 of 2	0	0	82	0	3	0	0	7	92
2-1 Otter Trawl 2 of 2	0	5	263	1	6	2	15	0	292
June Subtotal	0	15	752	2	25	4	55	20	873
Date: 29 July									
2-1 Otter Trawl 1 of 2	0	0	8	0	0	0	0	4	12
2-1 Otter Trawl 2 of 2	0	0	23	0	0	0	0	0	23
1B-1 Otter Trawl 2 of 2	0	0	1	0	0	0	0	0	1
July Subtotal	0	0	32	0	0	0	0	4	36
Total larval fish 2005	6	16	791	7	25	4	55	24	928

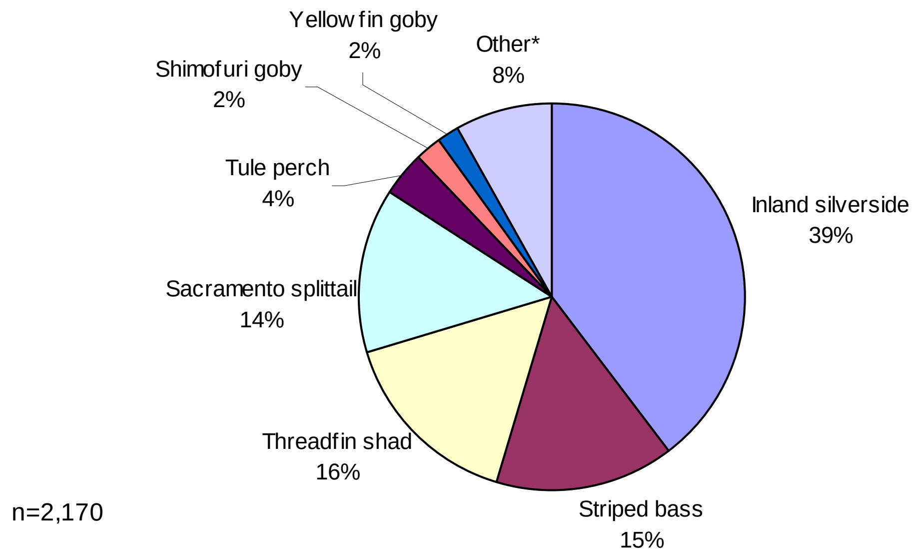


Figure 3-1. Composition of juvenile and adult fish captured in the Napa River Project area in 2005.

* Species comprising less than 1 % of the catch: American shad, bluegill, carp, chum salmon, long-jaw ed mudsucker, Pacific herring, prickly sculpin, rainw ater killifish, staghorn sculpin, Sacramento sucker, starry flounder, steelhead, threespine stickleback, w hite crappie.

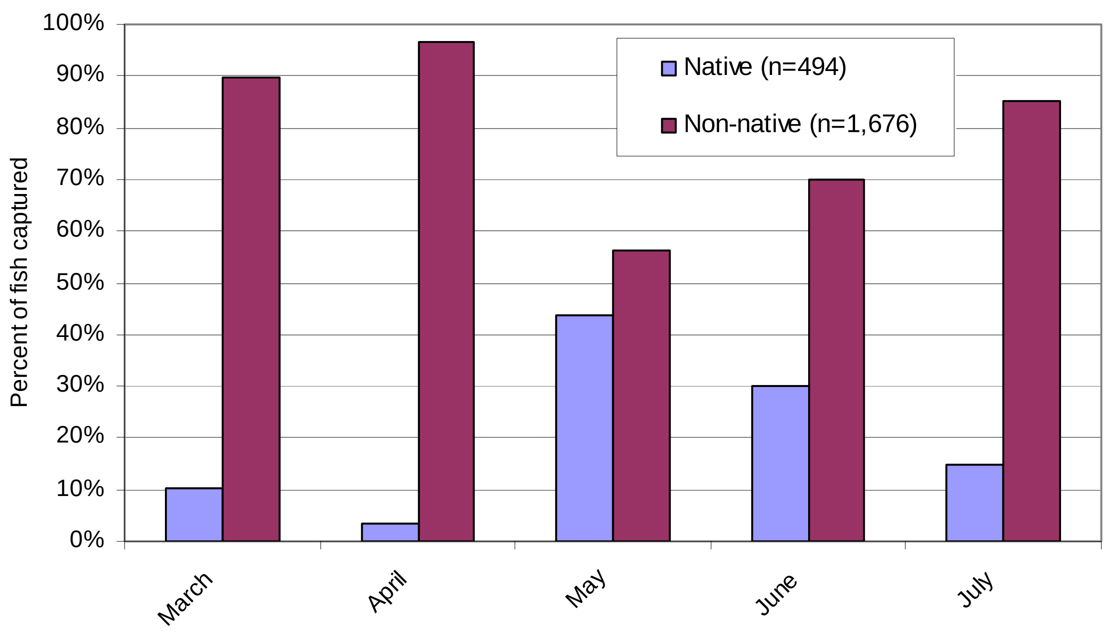


Figure 3-2. Percent of native and non-native fish captured in 2005 by month in the Napa River Project area.

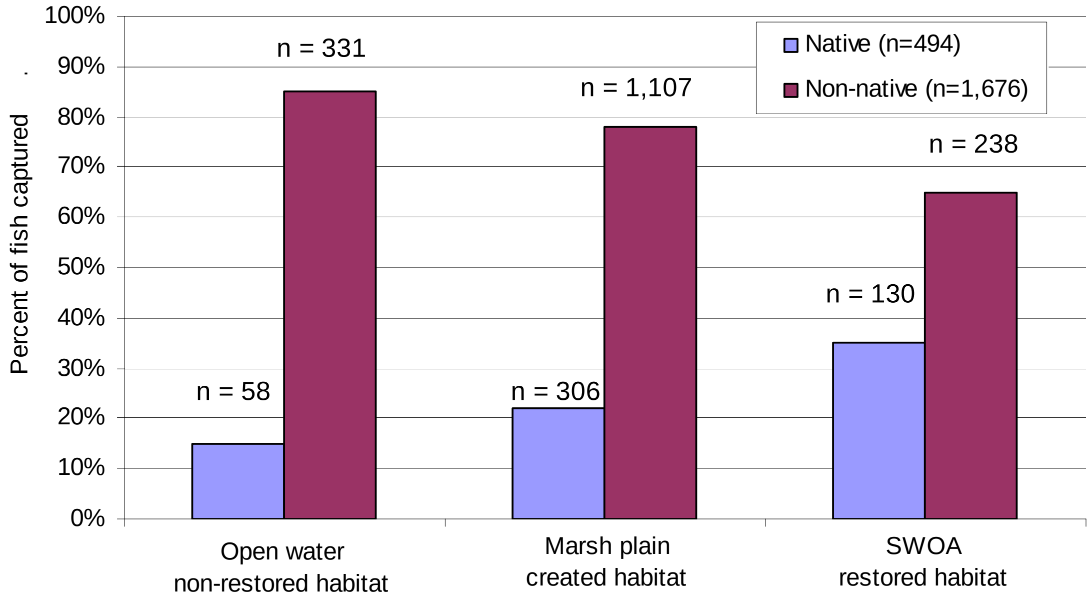


Figure 3-3. Percent of native and non-native juvenile and adult fish captured in all habitat types in the Napa River Project area in 2005.

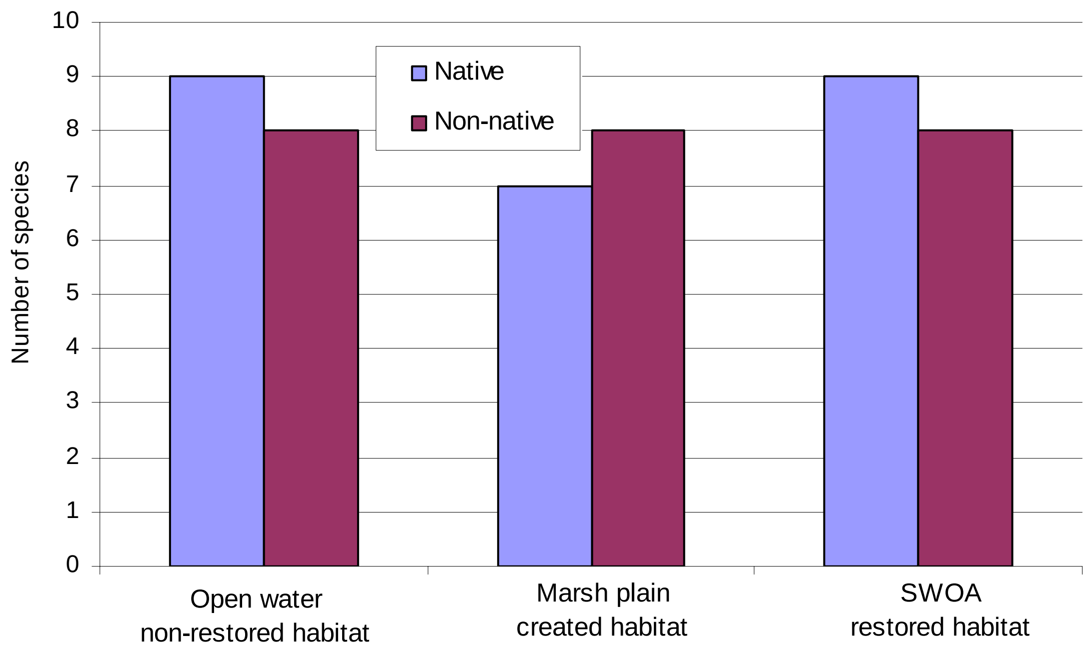


Figure 3-4. Number of species captured by habitat type in the Napa River Project area in 2005.

Table 3-3. Napa River Fisheries Monitoring Program: Monthly Average Environmental Conditions in 2005.

Month	Location	Water Depth [m (ft)]	Water Temperature Surface [°C (°F)]	Water Temperature Bottom [°C (°F)]	Water Turbidity [Secchi Depth] [m (ft)]	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Daily Mean Flow (cfs)*
Mar-05	Open Water	4.7 (15.4)	14.8 (58.6)	14.4 (57.9)	0.6 (2.0)	9.6	9.5	0.1	0.1	700
	SWOA	0.9 (3.0)	13.7 (56.7)	13.7 (56.7)	0.3 (1.0)	8.4	7.6	0.3	0.3	
	Marsh Plain	0.6 (2.0)	14.8 (58.6)	14.5 (58.1)	0.5 (1.6)	9.5	9.6	0.1	0.1	
Apr-05	Open Water	4.8 (15.8)	17.0 (62.6)	16.7 (62.1)	0.9 (3.0)	9.4	9.7	0.5	0.6	299
	SWOA	1.2 (3.9)	17.6 (63.7)	17.4 (63.3)	0.4 (1.3)	8.4	7.8	1.5	1.6	
	Marsh Plain	0.4 (1.3)	18.2 (64.8)	17.9 (64.2)	0.7 (2.3)	10.4	10.8	0.2	0.2	
May-05	Open Water	3.5 (11.5)	17.9 (64.2)	17.8 (64.0)	0.5 (1.6)	7.6	7.2	1.2	1.2	275
	SWOA	1.4 (4.6)	18.1 (64.6)	18.1 (64.6)	0.3 (1.0)	5.4	5.7	1.7	1.7	
	Marsh Plain	0.4 (1.3)	18.6 (65.5)	18.4 (65.1)	0.3 (1.0)	8.5	8.4	0.5	0.5	
Jun-05	Open Water	4.5 (14.8)	22.9 (73.2)	22.2 (72.0)	0.3 (1.0)	6.6	7.0	1.2	1.4	57
	SWOA	1.0 (3.3)	20.7 (69.3)	20.8 (69.4)	0.3 (1.0)	5.4	5.3	3.8	3.8	
	Marsh Plain	0.4 (1.3)	22.8 (73.0)	22.7 (72.9)	0.3 (1.0)	6.5	6.9	1.7	1.7	
Jul-05	Open Water	4.1 (13.4)	24.2 (75.6)	23.6 (74.5)	0.5 (1.6)	6.2	5.4	6.3	7.2	13
	SWOA	0.8 (2.6)	23.1 (73.6)	23.2 (73.8)	0.6 (2.0)	5.9	5.1	9.5	9.5	
	Marsh Plain	0.6 (2.0)	24.0 (75.2)	23.9 (75.0)	0.5 (1.6)	6.2	5.9	6.5	7.1	

* Measured at USGS Napa River gaging station near Napa (#11458000).

3.3 State and Federally Listed Species

Reporting requirements were established as part of the take permit for listed species (steelhead, delta smelt, and Sacramento splittail). Sacramento splittail were removed from the list of threatened species by the USFWS on 22 September 2003 (USFWS 2003) and are currently considered as a federal and state listed species of special concern. During the 2005 field effort, Sacramento splittail, longfin smelt, and chum salmon (each state-listed species of special concern) were captured. In 2005, steelhead was the only federally listed species captured.

Steelhead

Five steelhead were captured in 2005; the dates, locations, and environmental conditions were recorded at the time of capture are provided in Table 3-4. All steelhead were weighed, measured, photographed, and released unharmed. The National Marine Fisheries (NMFS), part of the National Oceanic and Atmospheric Administration (NOAA), and California Department of Fish and Game (CDFG) were notified.

Steelhead captured at Site 3-1, May 2005.

Table 3-4. Steelhead captured in the Napa River in 2005.

Date	Site	Gear	Habitat type	Fork length [mm (in)]	Environmental Conditions		
					Temperature [^oC (^oF)]	Salinity (ppt)	Dissolved oxygen (mg/l)
23 March	1A-6	Fyke net	Restored SWOA	140 (5.5)	12.0 (53.6)	0.3	7.8
5 May	2-2	Beach seine	Created marsh plain	175 (6.9)	21.1 (69.9)	0.2	10.4
18 May	3-1	Purse seine	Open water	266 (10.5)	16.4 (61.5)	0.1	8.4
19 May	1A-3	Beach seine	Created marsh plain	68 (2.7)	17.5 (63.5)	0.1	7.7
19 May	1B-2	Beach seine	Created marsh plain	59 (2.3)	15.9 (60.6)	0.1	7.9

Chum salmon

In 2005, 31 juvenile chum salmon were captured in March, April, and May, primarily in the created marsh plain habitat (81 percent) and the restored SWOA (16 percent). One individual was captured in the open water habitat at the upstream-most site on the Napa River (Site 3-1). A few individuals were preserved to confirm the identification. Chum salmon had not previously been documented in the Napa River watershed before 2004 surveys conducted as part of the FMP. In 2004, Dr. Peter Moyle's laboratory at the University of California at Davis confirmed a sample individual to be a chum salmon. In 2005, juvenile chum salmon identification was confirmed by John Stadler of NMFS at the Washington State Habitat Branch and Chris Howard of Green Diamond Resource Company, both of whom have extensive experience distinguishing juvenile chum and Chinook salmon.

Sacramento splittail

During the 2005 field effort, 305 Sacramento splittail were captured (Table B-1). Splittail were caught in March, May, June, and July, and in all habitat types, including open water, marsh plain, and SWOA with the beach seine, fyke net, and otter trawl (Table 3-5; Figures A-11 through A-16).

Sacramento splittail were examined for their reproductive state at the time of capture. Of the 305 splittail captured in 2005, 8 adults showed no evidence of spawning (no eggs or milt were observed with pressure applied to the abdomen), 1 adult had spawning colors but no evidence of spawning, 1 adult male had evidence of spawning, and 295 were identified as juveniles. The mature male was observed in late March. Adult Sacramento splittail with no evidence of spawning were all observed in May. Juvenile Sacramento splittail were most abundant in June 2005. A total of 762 splittail were captured in the FMP field effort from 2001–2005. Adults were most abundant between February and April, and juveniles became more abundant between May and July (Figure 3-5).

Sacramento splittail captured at Site 1A-2, April 2005.

Sacramento splittail were most abundant in May and June in 2005 (Figure A-11), with the majority comprised of juveniles. The CPUE of splittail captured by each gear type varied with habitat type (Figures A-12 through A-15). In 2005, the CPUE of splittail captured by otter trawl was higher in the restored SWOA than in the main channel, and the beach seine had a higher CPUE in the created marsh plain terraces than in the restored SWOA in late May and June. In 2005, the fyke net had the highest CPUE (fish/minute) in early May, which was also substantially higher than previous years (Figure A-15). In 2005, the beach seine had the highest CPUE (fish/m^3) in June (Figure A-16). The most successful gear type for capturing splittail during the five years of monitoring was the beach seine (82 percent), followed by the otter trawl (9 percent), fyke net (8 percent), and purse seine (1 percent) (Figure A-17).

There appears to be a close association between juvenile splittail and shallow water habitat. Throughout the FMP, although juvenile splittail were observed in open water habitat, the majority (97 percent) were captured in shallow marsh plain or SWOA habitats. Adult splittail were most abundant in the deeper open water habitat (42 percent), although they were also observed in the shallow SWOA (30 percent) and marsh plain (26 percent) habitats.

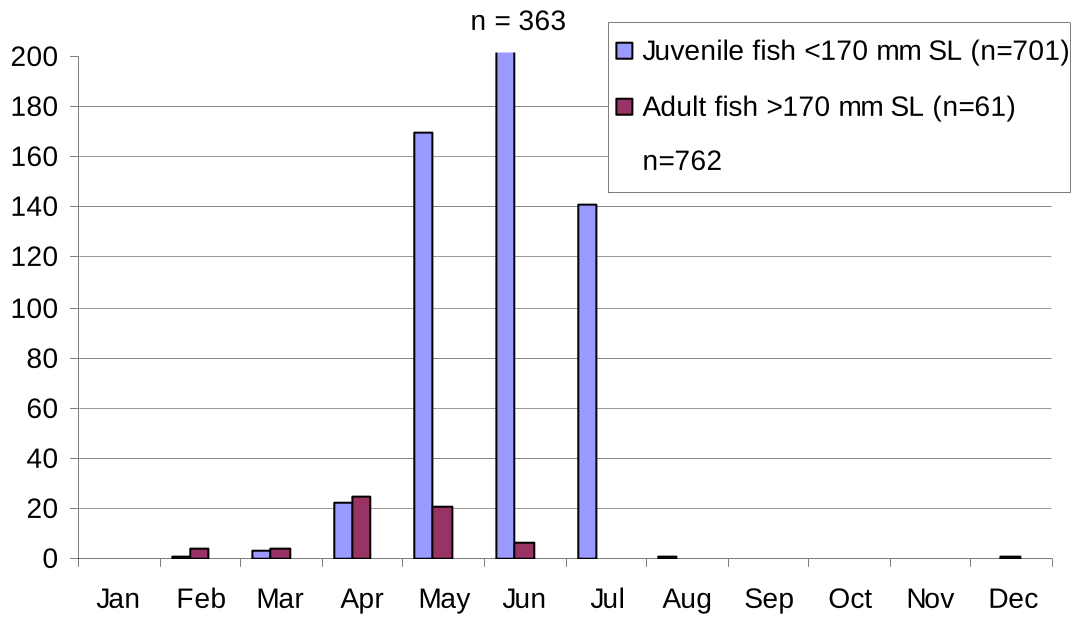


Figure 3-5. Juvenile and adult Sacramento splittail captured in the Napa River Project area in July 2001-July 2002, January 2003-July 2003, March 2004-July 2004, and March 2005-July 2005.

Table 3-5. Sacramento Splittail Captured in the Napa River Project area in 2005.

Gear type:	Beach seine				Fyke net			Otter trawl				Purse seine	Total
Habitat type:	SWOA	Marsh plain			SWOA			SWOA	Main channel			Main channel	
Site:	1A-4	1A-3	2-2	1B-2	1A-6	1A-7	1A-10	1A-2	1B-1	2-1	1A-1	3-1	
Sampling event													
Early March													0
Late March		1					1	1					3
April													0
Early May	22	5		6	3	23		1	1				61
Late May	9	43	2	20	2	8	2	1					87
June	25	39	19	44		1		1	1				130
July		17	7										23
Total Per Site	56	105	28	70	5	32	3	4	2	0	0	0	305

Analysis of length-frequency data (Daniels and Moyle 1983) indicate that age 1+ splittail range from 111.4–171.2 mm, age 2+ fish range from 171.2–215 mm, and age 3+ fish range from 215–250 mm. In 2004 and 2005, young-of-year (YOY) were most abundant, but older age classes were also represented (Figure 3-6).

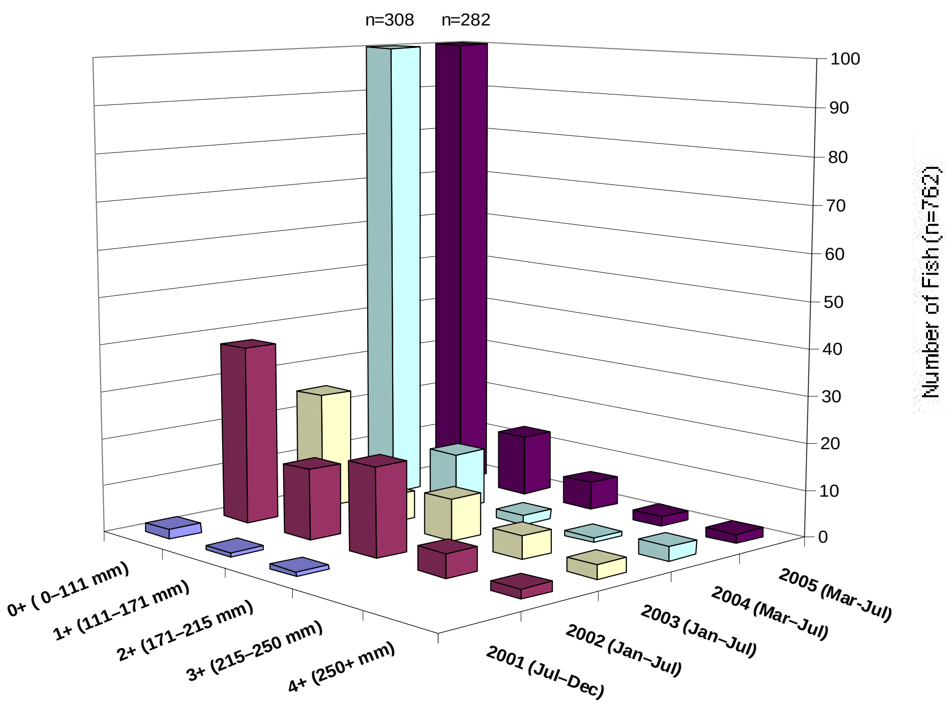


Figure 3-6. Age class and lengths of Sacramento splittail in the Napa River Project area in 2001–2005.

3.4 Vegetation Types

To increase bank stabilization along floodplain and marsh terraces, emergent vegetation was planted along the east side of the river, near Kennedy Park, New Tulocay Creek, and Soscol Avenue. The following species were to be planted: coyote brush, mule fat, mugwort, California wild rose, salmonberry, bulrush spp., common cattails, willow spp., Fremont cottonwood, box elder, Oregon ash, oak spp., and native perennial grasses (USACE 1999).

Non-native *Cotula coronopifolia* (brass buttons) inhabiting the SWOA, 2004.

Following the SWOA levee breach in June 2001, pasture vegetation began to rapidly convert to mud flats. In 2005, most of the SWOA was still in the early stages of transition from mud flats to estuarine aquatic vegetation. The substrate is currently mud with some vegetation, primarily consisting of previously established estuarine plants (such as tules, pickleweed, and algae). Photos taken at sampling sites in the SWOA reflect the rapid transformation from meadow to mudflats. This transition appears to be followed by a very gradual colonization by various aquatic and emergent estuarine plants, which in turn will provide habitat for various fish species and support aquatic food webs.

Plant species in the SWOA are typical of both salt and brackish marsh habitat (CH2MHill 2005). Brackish marsh vegetation occurs in the transitional zone between the tidally inundated mudflats and the adjacent grasslands that is inundated only during extreme high tides. Species identified included brass buttons, brass button thatch, spearscale, annual beard grass, alkalai heath, perennial ryegrass, curley dock, alkali weed, Mediterranean barley, bristly ox-tongue, pickleweed, saltgrass, fleshy jaumea, and gumweed. Additional species, identified on the eastern side of the SWOA along terraces on the edge of the Napa River included California bulrush, tule, and California aster.

Field observations estimated that tidal influence has been restored to approximately 351 acres, which includes 278 acres of mudflats, 28 acres of low marsh, and 45 acres of open water and tidal channels (CH2MHill 2005). This total amount is approximately 83–87 percent of the target acreage objective for restoration of tidal influence and marshland. Over time the extent of tidal inundation could become smaller and objectives may not be met without active management such as recontouring and vegetation manipulation (CH2MHill 2005). A more accurate investigation of the situation was recommended (CH2MHill 2005).

The brackish marsh acreage restoration target in the SWOA is 503 acres. Only 28 percent or 140 acres was mapped in 2004 (CH2MHill 2005). Brackish marsh species are expected to increase over time. However, conversion of other habitats such as open water, freshwater wetland, and uplands will be required to meet the goal of 503 acres (CH2MHill 2005). Recontouring and vegetation manipulation may be required for this to happen (CH2MHill 2005).

Native *Scirpus californicus* (California tule) inhabiting the SWOA, 2004.

The 278 acres of tidal mudflats that were created exceeds the target for the entire Napa River Flood Protection Project. This habitat is likely to be temporary and is expected to convert to brackish marsh over the long term (CH2MHill 2005). Planting will be required to establish riparian forest, shaded river habitat, and oak woodland habitats (CH2MHill 2005).

The primary goals to restore tidal influences and tidal marshland are gradually being met. Although the extensive mudflat is currently lacking emergent brackish marsh vegetation over much of its area, it has become a highly productive environment based on a variety of micro- and macro- algae carried by tidal currents. This has provided a food base for many invertebrates, which in turn provide food for many mammal, bird, and fish species.

Restoration of vegetation in the SWOA, 2005.

Restoration of tidal inundation and creation of wetland and other habitat types are expected to take place over the long term, which was defined as 40 years in the Mitigation and Monitoring Plan (CH2MHill 2005).

4 Discussion of 2005 Results

4.1 Fish Abundance and Distribution

In this section, fish species abundance, composition, and proportion of native and non-native fish species and distribution are compared between open water habitat, created marsh plain habitat, and recently restored SWOA habitat. General comparisons are made between the 2005 survey and the 2001–2004 FMP surveys. In addition, the results of the 2005 field efforts are compared with 21 years of surveys from nearby Suisun Marsh and Bay, located approximately 20 km southeast of the Napa FMP study area, to better understand fish species relationships to environmental variables in the Napa River. Although close in proximity, Suisun Bay differs from the Napa River and estuary because it is primarily influenced by inflows from the Sacramento and San Joaquin rivers.

Relative abundance

The species composition in 2005 was similar to that found from 2001–2004, although the most abundant species varied annually. In 2005, inland silverside continued to be the most abundant species captured, followed by threadfin shad, striped bass, and Sacramento splittail. Inland silverside were also the most abundant species in 2004, however threadfin shad were most abundant in 2003 and Pacific herring were most abundant in 2002 (Table B-1). The species collected in the Napa River were also collected in nearby Suisun Marsh; however, the order of relative abundance differed, with striped bass, inland silverside, yellowfin goby, and threespine stickleback being the most abundant (Matern *et al.* 2002). A variety of factors in the Napa River such as environmental conditions, numbers of spawning adults, spawning success and other variables may favor one species over another and influence yearly and seasonal abundance.

Native and non-native fish

The proportion of native and non-native fish in the Napa River study area varied seasonally, annually, and by habitat type. Non-native fish dominated the catch between March and July 2005 in the open water, marsh plain, and SWOA habitat types, with native fish representing a larger percentage of the catch in May and June. Similarly, from 2001 to 2004, non-native fish dominated the catch except when juvenile Pacific herring were abundant in April 2002 and April 2003 (USACE 2003b and USACE 2004). During the 2001–2005 sampling period, non-native fish ranged from 13 to 98 percent of the catch per year. Non-native fish were the most abundant during summer and winter 2001. Non-native species represented 61 percent of the overall FMP catch from 2001–2005.

Tule perch captured at non-restored Site 2-1, November 2001.

To date, the FMP project has documented the presence of 37 species (20 native, 54 percent) in the study area, as compared to the 53 species (28 native, 52 percent) found in

Suisun Marsh by Matern *et al*. (2002). The percentage of native species found in the two studies is similar. The Napa River feeds into San Pablo Bay, which is part of the San Francisco Estuary and is considered one of the most disturbed aquatic ecosystems in North America (USFWS 1995).

Populations of native fish species that are only seasonally present in Suisun Marsh (e.g., longfin smelt and delta smelt) appear to be experiencing long-term declines (Matern *et al.* 2002, Bennett 2005). Populations of Sacramento splittail, a year-round resident, have decreased since 2001, although a general increase has been observed since 1994 (Stover *et al*. 2004). In addition, Sacramento sucker, another year-round resident, appears to have declined and then stabilized at lower numbers (Matern *et al.* 2002). Non-native species that tend to be found in Suisun Marsh year-round (e.g., striped bass, yellowfin goby, shimofuri goby, carp, white catfish, inland silverside) have exhibited no clear trends in long-term abundance (Matern *et al*. 2002). Due to the short-term duration of the FMP and associated Napa Project, no strong conclusions regarding long-term trends in abundance of fishes in the Napa River estuary can be made at this time.

Inland silverside

Inland silverside were the most abundant species captured in 2001 (88 percent), 2004 (81 percent), and 2005 (40 percent), and were abundant during all seasons. All life stages of inland silverside were observed throughout the FMP sampling area. Inland silversides are fractional spawners, most spawning and dying within first or second summer of life (Moyle 2002). Throughout the FMP, inland silversides were most abundant in the shallow water SWOA and marsh plain habitats (92 percent). Inland silverside was less abundant in deep open water habitat (8 percent). They were the second-most abundant species captured in Suisun Marsh beach seine surveys (Matern *et al*. 2002) and are considered to be the most abundant fish inhabiting shallow water in the San Francisco Estuary (Moyle 2002).

Threadfin shad

Threadfin shad was the second most abundant species in 2005 (16 percent) and in 2003 (53 percent). Adults, larger than 60 mm standard length at the end of the first year (Moyle 2002), were the most abundant life stage captured throughout the FMP, although all life stages were captured. The life span of threadfin shad is two years and average length at this age is 100 mm SL (Moyle 2002). The Napa River may provide optimal growth for threadfin shad, as during the spring and summer sampling months of the FMP, threadfin shad larger than 120 mm and up to 155 mm fork length were captured. Threadfin shad were most abundant in both the open water and marsh plain habitat in July 2005 when water temperatures were warm [22.4–22.9°C (72.3–73.2°F)]. The water temperatures in

Threadfin shad captured in the created habitat Site 1B-2, May 2005.

July are within the 22–24^{o}C (71.6–75.2^{o}F) range which provides optimal survival and growth for threadfin shad (Moyle 2002). Similar to 2003, threadfin shad were most abundant in the shallow marsh plain terraces, although also abundant in open water habitat in July [25.9–26.1^{o}C (78.6–78.9^{o}F)]. Throughout the FMP, threadfin shad were abundant in the marsh plain terraces and open water habitat in July when temperatures were warm, although less than 5 percent were observed in the restored SWOA.

Striped bass

Striped bass captured at Site 1A-2, 2005.

Striped bass (mostly juveniles) were the third most abundant species captured in 2005 (15 percent). They were most abundant in marsh plain sites sampled by the beach seine in June and open water sites sampled by otter trawl in July 2005. They were also the most abundant fish captured in open water sites in 2004 (24 percent), with the highest numbers captured in April and May. Similarly in 2003, 85 percent of the striped bass were captured in open water sites, although the highest numbers were captured in July. In Suisun Marsh, striped bass were most abundant in June (Matern *et al*. 2002) and the majority of the striped bass captured were juveniles (Stover *et al.* 2004). Although striped bass was the most abundant species captured in Suisun Marsh, the number of juvenile striped bass appears to be declining significantly over the long term (Matern *et al*. 2002). Striped bass may spawn in the Napa River, although spawning has not been documented. Their main spawning area is the nearby Sacramento River (Moyle 2002). Striped bass are known to rear in Suisun Bay (Stevens *et al*. 1985, as cited in Moyle 2002) and based on the FMP surveys, the capture of larval and juvenile striped bass suggests that spawning and rearing likely takes place in the Napa River.

Sacramento splittail

Sacramento splittail was the fourth most abundant species and the most abundant native species captured from March through July 2004 (11 percent) and 2005 (14 percent). Splittail was also one of the most abundant species captured in Suisun Marsh (Matern *et al*. 2002). In 2005, juvenile splittail were most abundant in May and June. The majority of splittail were juveniles captured on the created marsh plain terraces (65 percent) and the restored SWOA (31 percent). As in 2004, the high numbers of juveniles (n= 295) captured in 2005 suggest another strong year class. Because only 11 of the captured splittail were adults, it is likely that the splittail are spawning earlier in the year or further up in the watershed. The high numbers of juvenile Sacramento splittail captured indicate that they are using the marsh plain terraces for rearing, most likely to forage and escape from larger predators found in open water habitat.

The abundance of splittail varied annually between 2002 and 2005. Splittail were not commonly captured in 2002 and 2003. In 2002, 79 splittail were captured in the Project area compared to 48 captured in 2003, 326 in 2004, and 305 in 2005. Seasonal abundance of Sacramento splittail in both 2002 and 2003 increased beginning in April, peaked in June, and then declined in July. In 2004, the greatest abundance of Sacramento splittail (comprised mostly of juveniles) occurred in July 2004. In 2005, juvenile splittail numbers began increasing in May and peaked in June. In contrast, in Suisun Marsh the numbers of splittail of all sizes captured remained consistent throughout the year (Matern *et al.* 2002).

Adult and juvenile splittail appear to use different habitat types. During the course of the FMP, adult splittail were typically captured in deep, open water, whereas juveniles were typically captured in the shallower SWOA and marsh plain habitats. Similarly, young-of-the-year splittail were caught in large numbers in shallow water habitats sampled by beach seines in Suisun Marsh from June to September (Matern *et al*. 2002).

Spawning of Sacramento splittail, which occurs primarily from March through May, is believed to be triggered by rising temperatures in the spring (Moyle 2002). Spawning habitat consists of slow-moving reaches in large rivers, flooded vegetation in tidal freshwater, and in estuarine marshes and sloughs (Moyle 2002). Shallow water habitats, such as inundated floodplains, provide important spawning, rearing, and foraging habitat for Sacramento splittail (Sommer *et al.* 1997 and. 2002). Splittail have been abundant in the Napa Marsh during wet years and rare or absent during low discharge years (Moyle *et al.* 2004).

All life stages of splittail have been captured within the study area. This study, along with the 2001 CDFG 20-mm tow-net surveys, successfully captured splittail of various size and age classes, including larvae, and age 0, 1+, 2+, and 3+ fish. Sexually mature adults (typically age 2+ and greater) were identified by their spawning coloration or the presence of milt and eggs. The presence of mature adults indicates that spawning is likely occurring in or near the project area.

Restored Site 2-2, 2005.

Pacific herring

Only 16 juvenile Pacific herring were captured in 2005 compared to 30 captured in 2004, and 648 in 2003. In 2002, juvenile Pacific herring was the most abundant species (n=3,338, 75 percent) captured. Pacific herring may be using the restored SWOA for rearing. Throughout the FMP the herring were most abundant in the restored SWOA habitat (95 percent) compared to the created marsh plain terraces and open water habitat. Lower numbers of juvenile herring in our surveys since 2002 may reflect lower adult spawner abundance, or reduced spawning success in the San Francisco Bay area during those years.

In San Francisco Bay, Pacific herring spawn adhesive eggs on seagrasses and other substrates along the shoreline in intertidal and shallow subtidal areas primarily from the Richmond-San Rafael Bridge in the north to Candlestick Point in the south (Watters *et al.* 2001). Based on the size of Pacific herring captured between 2002 and 2005, the age was estimated to be two to three months (Johnson Wang, USBR, pers. comm., 2005). Pacific herring are transported by tides into the upper estuary of San Francisco Bay, which includes the Napa River and Suisun Marsh to be used as extended nursery areas (Johnson Wang, USBR, pers. comm., 2005).

Pacific herring captured at Site 1B-1, July 2003.

Similar to the high capture rate of Pacific herring in 2002 and 2003 on the Napa River, the largest catch (since 1979) of Pacific herring was observed in Suisun Marsh in 2001 (n=56), 2002 (n=42), and 2003 (n=133) (pers. comm., 2005, Robert Schroeter, University of California at Davis and Stover *et al*. 2004). Prior to this recent abundance of Pacific herring, this species made up less than one percent of total catch in Suisun Marsh (Matern *et al.* 2002).

Longfin smelt

Larval longfin smelt show strong annual variation in the study area, with smelt not as abundant in 2005 compared to prior sampling years. Low numbers of larval longfin smelt were incidentally captured in the study area in 2002 (n=5, 1 percent of total larval catch), 2004 (n=20, 20 percent), and 2005 (n=5, <1 percent) and with higher numbers in 2003 (n=3,547, 88 percent) and 2001 (n=932, 55 percent) (USACE 2003b, USACE 2004). These larval longfin smelt were captured in both the restored SWOA (47 percent) and open water (54 percent) habitats. The majority (98 percent) of the longfin smelt captured in the FMP (2001–2005), were captured in March and April 2003. Longfin smelt was also the most abundant larval fish captured in CDFG's 20-mm tow-net trawls in open water habitat (over 30,000) in March, April, and May 2001 (USACE 2002). Larval longfin smelt were captured when water was the freshest (salinity ranging 0.4–5.6 ppt) in March–May 2001 and March–May 2003.

Longfin smelt, captured in the restored SWOA, December 2001

Based on the high abundance of larval longfin smelt, spawning is likely occurring in or near the study area. Longfin smelt concentrate in San Pablo Bay in April-June, and move upstream to spawn in fresh water (Moyle 2002). Spawning has been documented in the estuary below Medford Island in the San Joaquin River and in the nearby Sacramento River below Rio Vista (Moyle 2002). The decrease in the number of longfin smelt captured in 2004 and 2005 may be due to decreased abundance of spawning adults near the study area. The general trend of longfin smelt in Suisun Marsh appears to be decreasing (Stover *et al*. 2004).

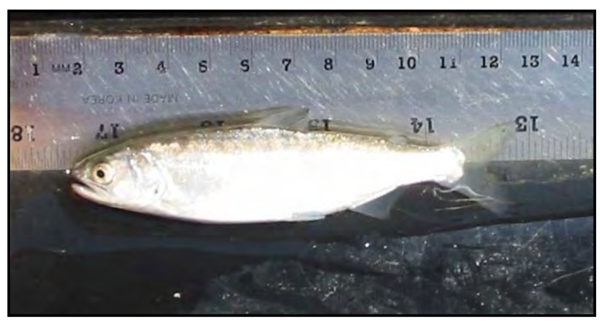
4.1.1 State and federal listed species

Sacramento splittail

Sacramento splittail was removed from federal listing in 2003, but remains a species of special concern in California. Recently, genetic differences were documented among splittail in the Napa, Petaluma, and Sacramento/San Joaquin River systems (Melinda Baerwald and Bernie May, UCD, pers. comm., 2004). Genetic differences between Sacramento splittail populations could have resulted from reproductive fidelity and basin-specific adaptation to environmental conditions. The Napa/Petaluma Sacramento splittail population is important because this unique population may contain adaptive alleles that allow this population to survive an environmental change, while another population (in a neighboring river) becomes extirpated (Melinda Baerwald and Bernie May, UCD, pers. comm., 2004). Based on splittail monitoring in the Suisun Marsh, catch increased from 1994–2001, and has declined since then (Stover *et al*. 2004).

The results of the FMP suggest strong year classes in 2004 and 2005. This may be due, in part, to the restoration and creation of shallow water habitat used by juveniles for rearing. The majority of Sacramento splittail captured throughout the FMP were captured in restored SWOA (25 percent) and created marsh plain (68 percent) habitats. The greatest abundances of Sacramento splittail captured in Suisun Marsh were also captured in shallow habitats (Stover *et al*. 2004). Continued monitoring would provide additional information on long-term splittail population trends in the Project area.

Chinook salmon



Chinook salmon captured at Site 1A-7, May 2003.

No Chinook salmon were captured in the Project area in 2005. In previous years, four Chinook salmon were captured; individuals were captured in April 2002 (clipped adipose fin), March 2003, May 2003, and March 2004. The adipose fin-clipped Chinook salmon may be from a hatchery release from the Sacramento/San Joaquin River system (Brown *et al.* 1996). The Mokelumne Hatchery releases 200,000–500,000 salmon fry with coded wire tags and adipose fin clips into the Shore Terminal, near Mare Island, between 15 April and 30 June (Bob Anderson, CDFG, pers. comm., 2005). The Feather River Hatchery releases 800,000 fall-run Chinook salmon, of which 10 percent are coded wire tagged, into San Pablo Bay (Anna Kastner, CDFG, pers. comm., 2005). The Nimbus Hatchery also releases fall-run Chinook salmon into San Pablo Bay (Brown 2003).

The Napa River is not included in the NOAA Fisheries ESU maps for ESA listed Chinook salmon in California (NOAA 2005). Chinook salmon ESUs in the region include Sacramento River Winter-Run, California Coast, and the Central Valley Spring, Fall and Late-fall runs. Further investigations, such as conducting spawning surveys on the Napa River and genetic testing of juvenile fish collected in the Napa River would determine whether the juvenile Chinook salmon captured in the Napa River originate from any of these ESUs.

Delta smelt

Delta smelt, a state and federal listed species, dramatically declined in the early 1980s, although the exact cause of the decline is relatively unknown (Bennett 2005). Delta smelt spawn in fresh water, but prefer euryhaline habitats. Shortly before spawning, adult delta smelt disperse widely into river channels and tidally influenced backwater sloughs (Moyle 2002, Radtke 1966, Wang 1991). Spawning takes place in shallow, fresh, or slightly brackish water (Wang 1991), primarily in sloughs and along the shorelines of large rivers (Moyle 2002; USFWS 1995); however, spawning locations in the delta have not been identified and are inferred from larval catches (Bennett 2005). The spawning season varies from year to year and may occur from early winter (December) to mid-summer (July). Eggs are adhesive and demersal, and are usually attached to substrate (Moyle 2002; Wang 1991). In the main stem of the Napa River, the 2001 capture of larval delta smelt documented that spawning occurred in this area. Although rearing habitat requirements of delta smelt are unknown, one hypothesis is that shallow water areas with low salinity and dense patches of zooplankton in Suisun Bay constitute a vital nursery (Herbold *et.al.* 1992 and Moyle *et al.* 1992 as cited in Bennett 2005). After the June 2001 levee breach, the restored SWOA habitat would have provided similar low salinity and shallow water habitat for rearing larval delta smelt.

CDFG biologists captured thousands of delta smelt larvae during daytime 20-mm tow-net surveys in the main channel in 2001 (USACE 2002). Only one adult delta smelt was captured by fyke net in 2002 in the SWOA (1A-7), and none were captured in 2003, 2004, or 2005. Considering that thousands of larvae were captured in 2001, juveniles and/or adults were expected to be collected during the 2002–2005 sampling efforts. The capture of a single adult delta smelt may be due to several factors, including gear selectivity, movements of delta smelt, inter-annual variability in the habitat use throughout the Bay-Delta, habitat conditions, or low adult abundance. The mesh size used in these studies was not designed to capture larval delta smelt, although delta smelt were captured in otter trawls and beach seines with similar mesh sizes in Suisun Marsh (Matern *et al.* 2002). In addition, the daily or monthly sampling times may not have been conducive for sampling delta smelt. All sampling was conducted in daylight and at a similar phase of the tidal cycle, which may have decreased the opportunity to capture delta smelt. Alternatively, delta smelt may not have used these habitats between 2002 and 2005. To assess delta smelt abundance and distribution in the Project area, increased efforts to sample both larval and adult stages would be required. Conducting surveys at different times of the tidal cycle, at night, or use of different gear may be necessary to increase the probability of capturing delta smelt.

Steelhead

During fall through spring, winter-run steelhead generally enter spawning streams as sexually mature adults and spawn a few months later in late winter or spring (Roelofs 1985, Meehan and Bjornn 1991, Behnke 1992). In California, juvenile steelhead typically rear in freshwater for one to two years before migrating downstream to the ocean as smolts from April through June, typically at a lengths ranging from 150 to 200 mm (Meehan and Bjornn 1991). Steelhead return to their natal streams and spawn in their fourth or fifth year of life (Shapovalov and Taft 1954, Behnke 1992). A small percentage of returning adults may stray to non-natal streams for spawning

The Napa River historically supported a run of 6,000–8,000 steelhead (USFWS 1968). The run had declined to an estimated 2,000 adults by the late 1960s (USFWS 1968, Anderson 1969). The current run of steelhead is estimated to be less than 200 adults (J. Emig and M. Rugg pers. comm., 2000 as cited in Stillwater Sciences and Dietrich 2002). Steelhead spawning has been observed in Dry Creek, a tributary of the Napa River near the Project area (J. Cook, tenant, pers. comm., 2003). Juvenile steelhead have been documented in 26 streams in the Napa River drainage (USACE and Stillwater Sciences 2005 unpublished data, NCRCD 2005, and Ecotrust Environmental and Friends of Napa River 2001 and 2002).

NMFS included the Napa River within its Central California Coast steelhead ESU (NOAA 2005). This ESU extends from the Russian River to Aptos Creek and includes tributaries to San Francisco and San Pablo Bay eastward to the Napa River, excluding the Sacramento and San Joaquin river basins (NOAA 2005).

Seven steelhead have been captured to date. In May 2002, one outmigrating steelhead smolt (208 mm FL) was captured, and in April 2004, a juvenile steelhead (90 mm FL) was captured; both were captured in open water habitat at the uppermost site near downtown Napa. In March and May 2005, three steelhead smolts (140–230 mm FL) were captured in created marsh plain habitat and at the uppermost open water habitat site in downtown Napa. On 19 May 2005, two 0+ (59 and 68 mm FL) steelhead were captured in created marsh plain sites. By the time of capture, flows had increased from 129 cfs on 17 May to 540 cfs on 18 May, and to 1,737 cfs on 19 May. The two 0+ steelhead may have been displaced from rearing habitats further upstream on the Napa River or from tributaries to the Napa River.

Low steelhead capture rates may be due to gear inefficiency but more likely, low capture rates reflect low steelhead abundance in the Project area. A limiting factor analysis for the Napa River Basin (Stillwater Sciences and Dietrich 2002) indicated that habitat loss caused by channel incision primarily explains why current conditions are unfavorable for steelhead spawning. Under current conditions, fine sediment intrusion into spawning gravels is reducing permeability and likely decreases survival of steelhead eggs and alevins. Other factors that likely adversely affect steelhead survival in the Napa River basin include migration barriers such as dams, road crossings, and other blockages, warm summer temperatures, and lack of habitat-forming large woody debris. It is hypothesized that surface water diversions and ground water extraction are reducing pool volumes and creating intermittent stream conditions that trap juveniles in isolated pools and dewater riffles that limit macroinvertebrate production and food for rearing juveniles (Stillwater Sciences and Dietrich 2002). Also, the potential for estuary rearing may have been seriously reduced due to diking and dredging.

Chum salmon

Chum salmon are a state listed species of special concern (CDFG 1995). Spawning occurs in either intertidal areas or within 200 km (125 mi) of the ocean (Moyle 2002). Due to the low abundance of chum salmon captured in the delta system, information on habitat use in this system is scarce. In Alaska, juvenile chum salmon spend a short time in fresh water and spend a longer time time in estuaries before migrating to the ocean (Moyle 2002). Past observations suggest that chum salmon may have a greater tendency to stray than other salmonid species (Johnson *et al.* 1997a). To date, 39 juvenile late fall-run chum salmon were captured between March and April 2004 and March and May 2005. It is not known whether these fish are progeny of fish that spawned naturally in the Napa River, the Sacramento/San Joaquin Rivers, or in other watersheds in San Francisco or San Pablo bays.

Recent sightings of chum salmon have been documented in central California. Mokelumne River Hatchery biologists documented chum salmon in 2001 but no additional fish have been observed since (Bob Anderson, CDFG, pers. comm. 2005). At the Noyo Coho Salmon Station in Fort Bragg, a female chum was captured in December 2001 and a male was captured in December 2003 (Alan Grass, CDFG, pers. comm., 2005). Chum salmon have also recently been observed on Lagunitas Creek (Alan Grass, CDFG, pers. comm., 2005). Although chum salmon are occasionally observed in hatcheries, chum salmon have not been observed spawning during stream surveys in the northern San Joaquin or Sacramento River drainage (Moyle 2002).

Chum salmon, April 2004.

In California, chum salmon are included in the Pacific Coast ESU (Johnson *et al.* 1997b). Under the federal ESA, NMFS determined that chum salmon were not warranted for listing in the Pacific Coast ESU (NMFS 1998). This ESU includes all naturally spawned populations of chum salmon from the Pacific coasts of California, Oregon, and Washington, west of the Elwha River on the Strait of Juan de Fuca. Current maps for the Pacific Coast chum salmon ESU extend to slightly south of Crescent City, CA (NOAA 2005). The southern boundary of this ESU is uncertain. The capture of 39 juvenile chum salmon in FMP surveys in 2004 and 2005 may indicate that an extension of the southern boundary, to include the Napa River or the San Francisco/San Pablo Bay region, may be warranted.

4.2 Vegetation Types

At present, the substrate in the SWOA is mostly mud with some vegetation, including previously established estuarine plants (such as tules, pickleweed, and algae). Plant species in the SWOA are typical of both salt and brackish marsh habitat, and up to 17 species have been identified (CH2MHill 2005). The rapid transformation from meadow to mud flats in the SWOA that occurred after levee breaching, appears to be followed by a very gradual colonization by various aquatic and emergent estuarine plants, which in turn will provide habitat for various fish species and prey organisms.

Vegetation that has been re-established in the Napa River Project area and the SWOA is also providing habitat for terrestrial species. The area is attracting large numbers and a wide variety of shorebirds, waterfowl, and their predators, including peregrine falcons. This diversity of bird species using the SWOA indicates that salt marsh restoration efforts are proceeding towards attaining their goals.

Brackish marsh species are expected to increase over time. However, conversion of other habitats such as open water, freshwater wetland, and uplands will be required to meet goals and active management may be required for this to happen (CH2MHill 2005). Restoration of tidal inundation and creation of wetland and other habitat types is expected to occur over the long term, which was defined as 40 years in the Mitigation and Monitoring Plan (MMP) (CH2MHill 2005).

As the vegetation communities continue to mature, habitat conditions are expected to change for fish. Continued monitoring would clarify the relationship between vegetation restoration and fish communities.

4.3 New Zealand Mudsnail

New Zealand mudsnails (NZMS) were collected in the SWOA mud flats with a beach seine in July 2004, and CDFG subsequently confirmed the species identification. The snails were found in filamentous algal mats. The NZMS is a non-native species that is spreading rapidly throughout the western United States. The snail consumes native algal food sources and utilizes space, leaving less space for native macroinvertebrates. As a result, fish populations in areas invaded by NZMS are expected to decline due to low food availability.

A specific survey for NZMS was not conducted in 2005, but their presence is assumed to continue. To prevent potential spread of NZMS, field personnel followed the protocol created by California Department of Fish and Game for sterilization of sampling gear, waders, and other equipment used in the Project area.

4.4 Environmental Conditions and Habitat Use

4.4.1 Environmental conditions

Environmental conditions in the Napa River varied by season, habitat type, and year. As in previous years, temperatures and salinities increased from spring to summer as dissolved oxygen and flow decreased.

In 2003 and 2005, salinity did not appear to increase as rapidly as in 2002 and 2004. This may be associated with high and prolonged discharges from the Napa River in 2003 and 2005, which began during winter and persisted at high levels until May and June before declining. In 2001, 2002, and 2004, flows declined sharply by May. For March–June periods, the daily average discharges were 77 cfs in 2002, 204 cfs in 2003, 98 cfs in 2004, and 268 cfs in 2005. The highest daily discharge to date for the FMP (8,016 cfs) was observed in February 2004, which represents a two-year flood event on the Napa River.

Similar to previous years, as flow decreased, water temperatures increased from March to July 2005. In 2005, average temperatures were similar in the open water, marsh plain, and SWOA habitats, ranging from 14.3 to 23.7°C (57.7 to 74.7°F) depending on the month. Temperature did not appear to correspond to any particular habitat types or to discharge from the Napa River.

Water clarity in each of the three habitat types increased from March to July 2005. The non-restored open water habitat had higher water clarity during the sampling period. Water clarity in the restored SWOA habitat and created marsh plain habitat was relatively lower than the open water habitat. This may be due to tidal cycle inundation and dewatering of the shallow mud substrate. Water clarity in all three habitat types was highest in April 2005. Water clarity and discharge from the Napa River were not correlated (R^2=0.02).

Similar to previous years, dissolved oxygen decreased between March and July 2005. In 2005, the average dissolved oxygen recorded in the open water (7.8 mg/l) and marsh plain (7.3 mg/l) habitats were similar and slightly higher than the shallow SWOA (6.5 mg/l). The lower dissolved oxygen in the SWOA may be a result of the increased turbidity.

In Suisun Bay, environmental variables such as temperature, salinity, and freshwater flow were correlated with catch, but Matern *et al.* (2002) did not believe that correlation implied cause. In general, they noted that fish species' response to environmental variables appeared weak and hypothesized that younger life stages were affected by environmental variables more than juvenile or adult life stages. The relationship between species relative abundance and environmental variables for the Napa FMP is evaluated further in Section 5.

Starry flounder captured in non-restored Site 1A-1, September 2001.

Relative abundance of native and non-native fish species may shift on the basis of environmental conditions such as water temperature and salinity. Non-native fishes can tolerate warmer water temperatures better than native species (Moyle 2002).

4.4.2 Habitat use

Restored Habitat

Restored and created habitats consist of marsh plain sites along the main channel of the Napa River, and all sites located in the SWOA, which are separated but linked to the Napa River main channel by approximately 0.8 km (0.5 mi) of an oxbow channel. In the Sacramento-San Joaquin Bay Delta, intertidal areas appear to favor native fishes, compared to deeper subtidal areas, where non-native fishes are abundant (Brown 2003, Simenstad *et al.* 2000). In 2005, the shallow restored intertidal areas of the Napa River Project area provided habitat for both non-native inland silverside, striped bass, and threadfin shad, and native Sacramento splittail and tule perch.

SWOA habitats were used seasonally by native Pacific herring and Sacramento splittail, with larval Pacific herring using the SWOA in March and April, and juvenile splittail using the SWOA in May and June. Although juvenile splittail were captured in the SWOA, most juvenile splittail utilized shallow marsh plain habitats, possibly due to the easy access from the main Napa River channel.

Restored SWOA Site 1A-6, April 2005.

Adult Sacramento splittail were not captured in high numbers during the FMP, but of those captured, two mature adults captured in 2005 were observed in the SWOA, and two spawning adults captured in 2004 were observed in the open water habitat. Temperatures in the SWOA appear to be favorable during the spawning season; however, continually inundated vegetation is required as fertilized eggs must be submerged until they hatch (Moyle 2002). The majority of the SWOA does not provide consistently submerged vegetation, with exposure of vegetation occurring daily at low tides. The shallow water habitat in the SWOA mainly provides foraging and rearing habitat for juvenile splittail.

Adult and juvenile splittail were more abundant in marsh plain habitat than in SWOA or open water habitats, even though splittail were the most abundant species captured in the SWOA in May 2005. The marsh plain habitat type is typified by shallow water depth, along with temperatures and salinities similar to those measured in open water habitats, which is expected because marsh plains are adjacent to open water habitats and are tidally inundated. Although spawning adults and juveniles were captured in marsh plain areas throughout the FMP, the majority of fish caught were juveniles. Juvenile splittail may be using these marsh plain terraces to forage and to escape from predators in the open water habitats.

In the early stages of restoration, the SWOA appears to be utilized by non-native species. Inland silverside utilized the SWOA during all seasons. In 2001, 2002, 2003, and 2004, recently restored wetlands were initially dominated by inland silverside, similar to the pattern found during other evaluations of restoration projects in the Sacramento-San Joaquin Delta (Lindberg and Marzuola 1993, and England *et al.* 1990 as cited in Brown 2003). In 2005, inland silverside continued to dominate the catch in early spring until Sacramento splittail became more abundant and dominated the catch in May, threadfin shad and splittail in June, and striped bass in July.

During the FMP, the most abundant non-native species captured in the restored SWOA and created marsh plain were inland silverside and threadfin shad. Juvenile threadfin shad were primarily utilizing the restored marsh plain, whereas juvenile and adult life stages of inland silverside were utilizing the restored marsh plain as well as the SWOA.

Non-restored Habitat

In the Project area, historic land management has channelized and eliminated shallow water habitats. Sampled non-restored areas consisted of all sites located in deep, open water in the main channel. No shallow water habitats were sampled, because the majority of the non-restored Project area is deeper water habitat. Throughout the FMP, the average water salinity was typically higher in the deep, non-restored sites than in the SWOA or the restored marsh plain. In the deeper non-restored habitat, the salinity at the bottom of the water column was typically higher than at the surface. In 2005, the deeper non-restored areas appeared to be providing habitat primarily for non-native threadfin shad, striped bass, and inland silverside.

Open water habitat was dominated by juveniles of non-native species, particularly threadfin shad and striped bass. These species were mostly captured in June and July, as temperature and salinity began to increase as freshwater discharge decreased. The majority of threadfin shad and striped bass were found in open water habitats (47 percent); however, they were also captured in the shallow marsh plain (45 percent) and SWOA (8 percent) habitat.

In 2005 in the non-restored habitat, the abundances of non-native species were much greater than the abundances of native species. The two most abundant native species in the non-restored habitat in 2005 were tule perch and Pacific herring. Tule perch were captured primarily in July, although they were captured in the created and restored habitats in May and June. Although Pacific herring were captured in open water habitats in July, they were not observed in either created or restored habitats in 2005.

Non-restored Site 3-1, January 2003.

5 Analysis of the FMP-to-date

5.1 Methods

Relationships between fish abundance and environmental variables were analyzed, using basic multivariate linear modeling techniques as specified in the "Final Work Plan and QA/QC Plan for Implementation for the Year 2002 Napa River Fisheries Monitoring Program" (USACE 2001a). Data from 2002–2005 for Sacramento splittail, Pacific herring, inland silverside, and striped bass were used. Sacramento splittail was chosen as a cumulative analysis species because it was a federally listed species when this project was initiated, even though it was removed from federal listing in 2003. Pacific herring and inland silverside were selected because these two species dominated the overall catch. Striped bass was selected because it is an abundant species that may have impacts on native species. Delta smelt were omitted from the analysis because very few fish were captured (one fish during 2001–2005).

Some data were omitted from the multivariate linear modeling analysis due to either the seasonal timing or length of record. Data from 2001 were omitted because sampling was conducted during different seasons (July to December in 2001, versus January to July in 2002 and 2003, and March to July in 2004 and 2005). Data from Sites 2-2 and 1B-2 were also omitted, because these sites were established in 2002 and 2003, respectively, resulting in smaller data sets than those for the other sites.

All analyses were performed using the S-Plus 6 statistical package (Version 6.2.1, Insightful Corp., Seattle, WA, USA). For analysis purposes, habitats were classified into the following area types: open water (non-restored), SWOA (channel or restored floodplain), and marsh plain (created) (Table 5-1).

Table 5-1. Classification of area types for sites sampled (2002–2005) and used for the cumulative-program-to-date analysis, Napa River Fisheries Monitoring Program.

Site	Area Type Classification	Gear Type
1A-1	Open water	Otter trawl
1A-2	SWOA (channel)	Otter trawl
1A-3	Marsh plain (created)	Beach seine
1A-4	SWOA (restored floodplain)	Beach seine
1A-6	SWOA (restored floodplain)	Fyke net
1A-7	SWOA (restored floodplain)	Fyke net
1A-8*	SWOA (restored floodplain)	Fyke net
1A-9*	SWOA (restored floodplain)	Purse seine
1A-10	SWOA (restored floodplain)	Fyke net
1B-1	Open water	Otter trawl
2-1	Open water	Otter trawl
3-1	Open water	Purse seine

*Sampled in 2002 only.

The main purpose of this multivariate linear modeling analysis was to identify possible relationships between catch-per-unit-effort (CPUE, the response variable), and explanatory environmental parameters. Potential explanatory parameters were assigned into one of two groups, categorical or numerical variables, and included: a) categorical variables: gear type, year, season, and habitat area type; and b) numerical variables: turbidity, salinity, and temperature.

For salinity and temperature, the average of surface and bottom measurements was used in the analysis. Averages were used because the sampling methods could not distinguish if analysis species were associated with either the bottom or the surface. For the created marsh plain and SWOA habitats, the bottom and surface measurements were similar, but in deep open water habitats, surface and bottom measurement differences were greater (Table 3-3).

Many measurable quantities were not included. Water depth and tidal variables were not included because gear types were not deployed over the full range of depths, tidal stages, and tidal cycles. Napa River discharge was not included, due to the difficulty in separating its effect from those of other environmental variables. Dissolved oxygen was not included in the analysis since concentrations are related to temperature.

Catch-per-unit-effort, a measure of species abundance, was calculated as: $CPUE_i = C_i/E_i$, where C_i is the total catch and E_i is the total expended capture effort for a single given location and set of environmental parameters i. Site-specific capture effort was uniquely characterized for each gear type as:

Carp captured in the restored SWOA, 2001.

$$\boldsymbol{E}(\boldsymbol{F})_{\boldsymbol{ij}} = \boldsymbol{m}_{\boldsymbol{ij}}$$

for fyke (F) net sampling, where m_{ij} is the number of minutes that the fyke net was fished during sampling event j for a given set of environmental parameters i (beginning with slack tide);

$$\boldsymbol{E}(\boldsymbol{O})_{\boldsymbol{ij}} = \frac{\boldsymbol{r}_{\boldsymbol{ij}}}{\boldsymbol{c}} \cdot 2.5 \cdot 1$$

for otter (O) trawl sampling, where r_{ij} is the total number of rotations recorded on a General Oceanics flow meter per trawl j, c is a constant representing the calibrated number of rotations per meter, and 2.5 m and 1 m are the trawl opening dimensions respectively;

$$\boldsymbol{E}(\boldsymbol{B})_{\boldsymbol{ij}} = \boldsymbol{s}_{\boldsymbol{ij}} \cdot \boldsymbol{w}_{\boldsymbol{ij}} \cdot \boldsymbol{d}_{\boldsymbol{ij}}$$

for beach (B) seining during set j, where s_{ij} is the visually estimated linear distance (in meters) from the physical start of the seining event to the bank, w_{ij} is the visually estimated width (in meters) of the seining area, and d_{ij} is the visually estimated average water depth (in meters);

$$E(P)_{ij} = l_{ij} \cdot w_{ij} \cdot d_{ij}$$

for purse (P) seining during set j, where l_{ij} (in meters) and w_{ij} (in meters) are the visually estimated length and width of an approximately rectangular seining area, and d_{ij} (in meters) is the depth of the purse seine.

Total daily capture effort for a single location and set of environmental parameters was then calculated as:

$$E(gear)_i = \sum_{j=1}^{T} E(gear)_{ij} ,$$

where *gear* is gear type B, F, O, or P; j identifies the specific sampling event; and T is the total number of sampling events.

Water depth at the time of sampling was typically less than 1 m for habitat sampled by beach seine or fyke net, but water depth was greater than 1 m for habitat sampled by purse seine or otter trawl. Therefore, data from beach seine or fyke net sampling were considered to be representative of "shallow" water habitat, whereas data from purse seining or otter trawling were considered to be representative of "deep" water habitat.

Tule perch captured at Site 1B-1, July 2003

Separate linear model analyses were conducted for each gear type to examine the relationship between CPUE and the environmental variables among habitat area types (i.e., open water, marsh plain, and SWOA). Analyses were conducted separately for each gear type, because by necessity, effort was different for each gear type, and each method likely had a different capture efficiency. For Sacramento splittail and striped bass, only data from beach seine and otter trawl sampling were used. Pacific herring data were analyzed for all gear types, and inland silverside data were analyzed for all gear types except the otter trawl (Table 5-2). The objective of the analysis was to detect relationships between CPUE and environmental variables, and to determine if CPUE varied among habitat area types. Where possible, data were compared from non-restored and restored habitats sampled by the same gear type.

The variables temperature and salinity were clustered into one group, but season and turbidity were not grouped. Significant relationships of CPUE with either temperature or salinity were considered to be evidence of a relationship with both variables, since these variables are typically interrelated (R^2=0.42 for this study).

Sizes of Sacramento splittail and striped bass (fork length in mm) were compared in different habitat area types using a standard two-sample *t*-test. Sizes were only compared between different habitat areas sampled by the same gear type. The purpose of this comparison was to determine if these species' adult and juvenile life stages used habitat area types differently. Area types compared were shallow water habitats sampled by beach seine (SWOA floodplain and the created marsh plain on the main channel), and deeper water habitats sampled by otter trawl (open water and the SWOA channel).

5.2 Results and Discussion

5.2.1 Sacramento splittail

Juvenile Sacramento splittail were found to have greater abundance in created marsh plain habitat than in restored SWOA floodplain habitat. Beach seine CPUE was significantly higher within the created marsh plain habitat ($p = 0.0023$) (Table 5-2). Juveniles represented 94 percent of the Sacramento splittail catch by beach seine. Beach seine CPUE comparisons could not be evaluated between the created marsh plain or restored SWOA areas, and the non-restored open water habitat, because beach seines only sampled created and restored habitats that are shallow, and the otter trawl and purse seine sampled only deep, non-restored open water habitat.

Fyke net CPUE comparisons could not be evaluated between shallow water habitats, because fyke nets sampled only restored SWOA floodplain areas. However, within the restored SWOA floodplain, fyke nets captured only 61 Sacramento splittail in 2002–2005, of which 59 were juveniles. This observation of low Sacramento splittail captures is explained by either limited fish use of the sampled SWOA floodplain (which is supported by the beach seine data), and/or fyke nets were not an effective gear type for capturing Sacramento splittail. The majority of these fish were captured in 2005, possibly suggesting that the SWOA habitat is becoming more favorable for Sacramento splittail rearing over time, or that habitat conditions for spawning and early rearing supported increased production and/or survival of Sacramento splittail in the Napa River watershed.

Sacramento splittail abundance did not differ between habitat area types within deep water habitats (i.e., SWOA channel or open water), based on otter trawl data ($p = 0.9094$) (Table 5-2). The otter trawl catch primarily consisted of adults in 2002, 2003, and 2005 (64 percent), although in 2004, juveniles comprised the majority of the catch (77 percent) (Table 5-3).

Based on otter trawl data, more adult Sacramento splittail utilized deep water habitat in the Project area during 2002 than in any other year, since relative abundances of adult Sacramento splittail in 2003 and 2005 differed significantly from that in 2002 ($p = 0.0169$ and $p = 0.0096$, respectively) (Table 5-2). No statistical difference was detected between relative abundances in 2002 and 2004 ($p = 0.4631$), although the majority of the otter trawl catch was juveniles in 2004, in contrast to adults in 2002.

Juvenile Sacramento splittail numbers were similar in 2002 and 2003, with increased abundances in 2004 and 2005. No statistical difference in relative abundance was found between beach seine data of 2002 and 2003 (p=0.1602), although relative abundances in 2004 and 2005 were significantly greater than abundance in 2002 (p = 0.0025 and p = 0.0314, respectively). Based on the analysis of beach seine (p>0.8) and otter trawl (p>0.1) data, no seasonal difference in relative abundances of juvenile or adult Sacramento splittail were found.

Table 5-2. Values of coefficients and *p*-values for linear models fitted by gear type for Sacramento splittail, inland silverside, Pacific herring, and striped bass, Napa River Fisheries Monitoring Program, 2002–2005.[a,b,c] Bold type indicates statistical significance.

Gear	Coefficients	*p* values:							
		Sacramento splittail		**Inland silverside**		**Pacific herring**		**Striped bass**	
		Value	***p***	**Value**	***p***	**Value**	***p***	**Value**	***p***
Beach seine	Intercept	0.0306	0.4301	0.0283	0.4888	0.0463	0.2289	-0.0129	0.2924
	Year (2003)	0.0211	0.1602	0.0102	0.5168	-0.0229	0.1232	-0.0024	0.6025
	Year (2004)	0.0457	**0.0025**	0.0389	**0.0134**	-0.0187	0.1969	0.0001	0.9854
	Year (2005)	0.0376	**0.0314**	0.0032	0.8611	-0.0283	0.0980	-0.0037	0.4960
	Season (summer)	0.0021	0.9134	-0.0023	0.9102	0.0085	0.6511	0.0248	**0.0001**
	Season (winter)	-0.0019	0.8827	-0.0180	0.1939	-0.0179	0.1685	0.0009	0.8306
	Area (SWOA)	-0.0322	**0.0023**	-0.0022	0.8395	0.0088	0.3793	-0.0019	0.5476
	Salinity	0.0047	**0.0440**	-0.0008	0.7344	-0.0018	0.4250	-0.0021	**0.0048**
	Temperature	-0.0009	0.6803	-0.0001	0.9527	-0.0010	0.6468	0.0016	**0.0229**
	Turbidity	-0.0007	**0.0360**	-0.0001	0.8861	0.0000	0.9929	-0.0002	0.0607
	Overall model		**0.0022**		0.3130		0.5135		**0.0017**
	R^2	0.3390		0.1546		0.1232		0.3469	
Fyke net	Intercept			0.0190	0.6767	2.1738	**0.0264**		
	Year (2003)			-0.0033	0.8758	-1.3054	**0.0043**		
	Year (2004)			0.0070	0.7506	-1.2602	**0.0080**		
	Year (2005)			-0.0205	0.4049	-1.5787	**0.0031**		
	Season (summer)			0.0287	0.2557	0.5098	0.3374		
	Season (winter)			-0.0107	0.5830	-0.2673	0.5154		
	Salinity			0.0027	0.3431	-0.0618	0.2950		
	Temperature			-0.0029	0.2132	-0.0380	0.4331		
	Turbidity			0.0012	**0.0278**	0.0037	0.7415		
	Overall model				**0.0036**		0.1035		
	R^2			0.2723		0.1683			

Table 5-2 (continued). Values of coefficients and *p*-values for linear models fitted by gear type for Sacramento splittail, inland silverside, Pacific herring, and striped bass, Napa River Fisheries Monitoring Program, 2002-2005.[a,b,c] Bold type indicates statistical significance.

Gear	Coefficients	*p* values:							
		Sacramento splittail		Inland silverside		Pacific herring		Striped bass	
		Value	*p*	Value	*p*	Value	*p*	Value	*p*
Otter trawl	Intercept	0.0007	**0.0072**			-0.0006	0.8354	0.0000	0.9895
	Year (2003)	-0.0003	**0.0169**			0.0015	0.3136	0.0008	0.6808
	Year (2004)	-0.0001	0.4631			-0.0003	0.8426	-0.0007	0.7231
	Year (2005)	-0.0004	**0.0096**			-0.0001	0.9400	-0.0012	0.5839
	Season (summer)	0.0000	0.8239			-0.0010	0.5675	0.0058	**0.0110**
	Season (winter)	-0.0002	0.1818			-0.0022	0.1018	0.0005	0.7569
	Area (SWOA)	0.0000	0.9094			0.0003	0.8182	-0.0014	0.3895
	Salinity	0.0000	0.8076			0.0001	0.8286	-0.0001	0.6782
	Temperature	0.0000	0.7932			-0.0001	0.7146	0.0002	0.2340
	Turbidity	0.0000	0.1116			0.0001	**0.0441**	-0.0001	0.0937
	Overall model		**0.0207**				0.4182		**0.0313**
	R^2	0.1612				0.07931		0.1518	
Purse seine	Intercept			-0.0419	0.1911	-0.0060	0.6215		
	Year (2003)			-0.0022	0.8775	0.0006	0.9210		
	Year (2004)			0.0053	0.7218	-0.0008	0.8947		
	Year (2005)			-0.0008	0.9531	0.0058	0.2978		
	Season (summer)			0.0024	0.9003	0.0048	0.5235		
	Season (winter)			-0.0061	0.6261	0.0014	0.7777		
	Salinity			-0.0025	0.4464	0.0002	0.8421		
	Temperature			0.0029	0.1352	0.0003	0.6986		
	Turbidity			0.0000	0.6098	0.0000	0.9191		
	Overall model				0.6685		0.5980		
	R^2			0.2338		0.2557			

[a] *p*-values are based on t-tests for the coefficients and F-statistic computed for the overall model.

[b] Reference categories were: year (2002); season (spring); area (created marsh plain) for beach seine data, or area (open water) for otter trawl and purse seine data.

[c] R^2 = Proportion of the total variation of the CPUE explained by the fitted regression model.

Table 5-3. Numbers of adult and juvenile Sacramento splittail by gear type and year, Napa River Fisheries Monitoring Program, 2002–2005.

Gear Type	Year	Number of Adults			Number of Juveniles
		Spawning	Not Spawning	Total	
Beach seine	2002	2	6	8	40
	2003	2	10	12	23
	2004	0	0	0	160
	2005	0	6	6	253
	Total	4	25	29	472
Fyke net	2002	0	1	1	2
	2003	0	0	0	1
	2004	0	0	0	17
	2005	1	0	1	39
	Total	1	1	2	59
Otter trawl	2002	5	13	18	7
	2003	0	5	5	6
	2004	2	3	5	17
	2005	1	3	4	2
	Total	8	24	32	32
Purse seine	2002	1	2	3	0
	2003	0	0	0	1
	2004	0	0	0	0
	2005	0	0	0	0
	Total	1	2	3	1

In 2004 and 2005, juvenile Sacramento splittail abundance was high in shallow water habitat (98 percent of all juveniles captured were in shallow water habitat), which contrasts strongly with the relatively low abundance of adult Sacramento splittail during the same period. Only two of five adults captured in 2004, and two of 11 adults captured in 2005, showed evidence of spawning (i.e., spawning colors or milt/eggs); slightly more captured adults showed evidence of spawning in 2003 (two of 17 adults) and in 2002 (eight of 30 adults). The large numbers of juveniles captured in 2004 and 2005 could be accounted for by a number of factors, including successful spawning upstream or downstream of the Project area, saturation of carrying capacity at upstream rearing locations, greater juvenile survival from 2003 to 2004 than in previous years, and/or continually improving rearing conditions in the SWOA and the created marsh plain. The decline of Sacramento splittail documented in Suisun Marsh from 1979 to 1999 was not exhibited elsewhere in the San Francisco estuary; one hypothesis explaining these observations was that localized spawning occurred outside of the marsh in some years, with more widespread spawning in others (Matern *et al*. 2002). A more intensive sampling effort would be needed to evaluate the distribution of Sacramento splittail spawning in the Napa River.

The abundance of juvenile Sacramento splittail may be associated with salinity. Juvenile Sacramento splittail data exhibited a significant relationship (p = 0.0134) between relative abundance and salinity within shallow water habitat (Table 5-2). The relationship may be specific to the Napa River estuary, however, the significance of the relationship could also be a statistical artifact, due to the short duration of this data set (4 years). Based on 21 years of sampling, no significant relationships were found between relative abundance of Sacramento splittail and any environmental variables in Suisun Marsh (Matern *et al*. 2002).

For Sacramento splittail, a significant relationship was exhibited between abundance and turbidity, which could be due to a number of factors, including increased capture efficiency (e.g., capture efficiency increased because turbidity decreased fish ability to see and avoid the sampling gear), a behavioral response (e.g., increased foraging under turbid conditions), or a simple statistical artifact. A change in the relationship between fish caught and effort complicates any kind of data interpretation between CPUE and environmental parameters, because the statistical model assumes that CPUE remains constant for a specific gear type.

5.2.2 Inland silverside

The data indicate that inland silverside did not use habitat area types differently. No statistical difference in relative abundance was detected between the SWOA floodplain and created marsh plain habitat, based on analysis of the beach seine data (p = 0.8395) (Table 5-2). Statistical analyses could not be conducted for habitat area type comparisons based on fyke net or purse seine data, because fyke nets only sampled SWOA floodplain habitat and purse seines only sampled open water habitat.

Fyke nets captured 366 inland silversides, the second highest total of any species captured by this gear type, from 2002 to 2005. Either the fyke net capture probability of inland silversides was much higher than that of the other species, and/or inland silverside were more abundant than the other species within the SWOA floodplain.

Seasonal differences in relative abundance of inland silversides were not detected. However, in Suisun Bay, inland silverside catches have been recorded as peaking in July, although no long-term pattern in relative abundance was observed (Matern *et al*. 2002).

There did appear to be differences in relative abundance of inland silversides in shallow water habitats between years. When comparing relative abundances between years 2002 and 2004, a statistically greater CPUE was found in 2004, based on beach seine data (p = 0.0134).

Inland silversides were found to be associated with turbidity but with no other environmental parameters. There was a significant positive relationship between fyke net CPUE and turbidity (p = 0.0278), potentially due to the same factors noted for juvenile Sacramento splittail.

Sampling restored SWOA Site 1A-7, 2001.

5.2.3 Pacific herring

Pacific herring were more abundant in 2002 compared with catches in 2003, 2004, or 2005. CPUE was significantly greater in 2002 than in any of the other years, based on the analysis of fyke net data ($p < 0.01$) (Table 5-2).

Pacific herring did not exhibit any clear relationships between abundance and environmental parameters. Based on analysis of data from otter trawl sampling, a significant relationship ($p = 0.0441$) was calculated between abundance and turbidity in deep open water habitat (Table 5-2); again, this relationship could be due to factors previously noted for Sacramento splittail and inland silverside (i.e., increased capture efficiency, foraging under more turbid conditions, or a statistical artifact).

5.2.4 Striped bass

Striped bass abundance did not appear to differ among years. There was no statistical difference in abundance when comparing relative abundance from 2003 to 2005 with 2002 for striped bass in any of the sampled habitats; this contrasts with the other non-native analysis species, inland silverside, which demonstrated a statistically significant increase in relative abundance from 2002 to 2004.

In shallow water habitats, more juvenile striped bass were captured during summer than in spring, as indicated by analysis of beach seine data ($p = 0.0110$). Most striped bass captured by beach seine (84 percent) were juveniles less than 80 mm FL. This observation is supported by data collected in Suisun Bay, in which the peak beach seine catch of juvenile striped bass was recorded in June (Matern *et al*. 2002).

Juvenile striped bass were associated with warmer temperatures. There was a significant relationship between beach seine CPUE and temperature within shallow water habitats for juvenile striped bass ($p = 0.0229$) (Table 5-2). In their 21-year study of Suisan Marsh, Matern *et al.* (2002) also found that juvenile striped bass exhibited a strong association with warmer temperatures.

Striped bass could prey upon other smaller fishes; being highly piscivorous, striped bass would likely count Sacramento splittail among their prey. Native Sacramento splittail have been historically found in great abundance, along with large striped bass populations (Moyle 2002). However in shallow water habitats, striped bass predation on juvenile Sacramento splittail appears unlikely in the Napa River. The majority (84 percent) of the striped bass captured in shallow water habitats were juveniles of similar size to juvenile Sacramento splittail. When tide elevation decreases and shallow water habitat becomes dewatered, fish “funnel” into the SWOA channel, where adult striped bass have been captured.

Based on otter trawl data, the relationship between striped bass relative abundance and turbidity approached statistical significance, ($p = 0.0937$). The relationship between striped bass abundance and turbidity is likely affected by the same factors that potentially affect similar relationships for inland silverside and Pacific herring (i.e., increased catch per effort under more turbid conditions, possible behavioral responses, or a statistical artifact).

5.2.5 Size distribution of Sacramento splittail and striped bass

Striped bass were larger in SWOA habitats. In the SWOA channel, striped bass were larger than in open water, based on striped bass data from 2002–2005 using a standard two-sample *t*-test ($p<0.0001$) (Table 5-4). Striped bass were also larger within the SWOA floodplain than in the created marsh plain ($p=0.0002$).

Younger juvenile Sacramento splittail (< 1 year) tended to use shallow water habitat area types, such as the SWOA floodplain and created marsh plain; older juveniles (> 1 year) tended to use deeper water habitat area types, such as SWOA channel and open water. Sizes of Sacramento splittail did not differ between the shallow water habitats; the sizes of Sacramento splittail between the shallow restored SWOA floodplain and the created marsh plain were not significantly different ($p = 0.0944$). In deep water habitats, Sacramento splittail sizes from the SWOA channel and the open water were not significantly different ($p = 0.2007$) (Table 5-4).

Table 5-4. Mean fork length (mm) and *t*-test results for Sacramento splittail and striped bass, comparing the SWOA floodplain to created marsh plain habitat (based on beach seine data), and open water to SWOA channel (based on otter trawl data), 2002–2005.

Species	Gear Type*	SWOA			Created marsh plain			Open water			*t*-test results**
		n	Mean FL (mm)	SD	n	Mean FL (mm)	SD	n	Mean FL (mm)	SD	*p*
Sacramento splittail	Beach seine	108	66.5	52.17	296	75.0	42.12	-	-	-	0.0944
	Otter trawl	14	207.0	91.81	-	-	-	51	177.6	70.41	0.2007
Striped bass	Beach seine	13	112.2	110.75	62	52.2	22.99	-	-	-	**0.0002**
	Otter trawl	77	172.5	111.89	-	-	-	407	118.3	66.41	**<0.0001**

*Comparison for beach seine was based on SWOA floodplain versus created marsh plain; for otter trawl, based on SWOA channel versus open water.

**two-sided test for the equality of means; significance level of 0.05.

5.2.6 Use of created and restored areas

Based on 2002 to 2005 data, Sacramento splittail use the created marsh plain and restored SWOA areas. Sacramento splittail sizes indicate that the vast majority of Sacramento splittail captured in the restored SWOA areas were juveniles (Figure 5-2). Sacramento splittail may be using the restored areas for rearing. Moyle *et al*. (2004) suggested that both stream margin and brackish water habitats were important for juvenile rearing; these types of habitat are represented in the created marsh plain and SWOA, respectively. However, based on beach seine data, Sacramento splittail commonly use the created marsh plain areas more than the restored SWOA floodplain areas. Sacramento splittail abundance as measured by CPUE was significantly higher in the created marsh plain than in the restored SWOA floodplain.

Inland silversides were abundant in newly created and restored areas, and their presence could be detrimental to native species because they are known to prey upon fish larvae, and may prey upon larval delta smelt (Moyle 2002). Indirect effects on growth and survival of other species are also possible, if these other species share the same prey base (Moyle 2002). In Suisun Bay, delta smelt and inland silverside were identified as co-occurring plankton-feeding fish (Matern *et al*. 2002).

Pacific herring are using the SWOA areas for rearing. The majority of herring (89 percent) were captured within the SWOA floodplain fyke net sites; the largest measured herring was 67 mm in fork length. No significant relationships were detected between CPUE and any of the environmental variables (Table 5-2). This suggests that the range of sampling seasons, salinity, turbidity, and temperature in the SWOA do not significantly affect use of the habitat by Pacific herring

Striped bass were found in created marsh plain and restored SWOA habitat. Striped bass captured in the SWOA habitat were typically larger than those captured elsewhere (Figure 5-1). Striped bass captured by otter trawl in the SWOA channel were significantly larger ($p < 0.0001$, mean length = 172.5 mm FL, n = 77) than in open water habitat (mean length = 118.3 mm FL, n = 407). Larger fish could be taking advantage of the increased feeding opportunities in the narrow SWOA channel, as prey move in and out of the floodplain as tides change. In 2004, a few larger striped bass individuals were also captured in created marsh plain areas, suggesting that predation on juvenile Sacramento splittail could be occurring in the created marsh plains. Larger striped bass were also found in open water habitats near created marsh plain terraces where the relative abundance of juvenile Sacramento splittail was highest. In the Sacramento-San Joaquin Delta, stomach contents of piscivorous fishes (largemouth bass, white catfish, and striped bass) included Sacramento splittail (Simenstad *et al*. 2000, as cited in Brown 2003).

Prior to 2005, smaller striped bass and Sacramento splittail used the main channel habitats (i.e., open water, created marsh plain) more than the shallow floodplain terrace or the deep channel in the SWOA, based on lengths of fish captured by otter trawl and beach seine (USACE 2005). However in 2005, smaller striped bass and Sacramento splittail (< 60 mm FL) were commonly captured in the restored SWOA areas, appearing to utilize these habitats nearly as frequently as the open water habitats (Figures 5-1 and 5-2). Based on otter trawl sampling, smaller striped bass utilize the deeper open water more frequently than the SWOA channel (Figure 5-1). Based on beach seine and otter trawl sampling, smaller Sacramento splittail utilize created marsh plain habitat more than deeper waters and shallow restored SWOA areas (Figure 5-2). The lower relative abundance of smaller fish in SWOA habitats suggests that the SWOA channel and floodplain are not as suitable for rearing habitat by young Sacramento splittail and striped bass. In addition, strong currents, lack of vegetative cover, and the relatively narrow outlet of the SWOA channel, may leave any smaller striped bass and Sacramento splittail that do utilize this area especially susceptible to predation. Adult Sacramento splittail use all habitats that were sampled by beach seine and otter trawl (Figure 5-2), whereas adult striped bass use primarily SWOA habitats and the deeper open water habitat (Figure 5-1). Larger Sacramento splittail and striped bass may be using the SWOA areas for foraging during high tides. Larger Sacramento splittail utilize the created marsh plain, whereas larger striped bass do not appear to use this habitat to any great extent.

Otter trawl capture probabilities for larger fish are likely to be higher in the SWOA channel than in open water habitat. The SWOA channel (Site 1A-2) can be more thoroughly sampled than the open water habitat, because the otter trawl can sample a relatively high proportion of the volume in the confined SWOA channel, which is approximately 9 m (30 ft) wide, compared to that of the main channel which is approximately 30 m (98 ft). Capture probabilities for smaller fish may be similar between the SWOA channel and open water; by being weaker swimmers, they are less likely to avoid the otter trawl. However, fewer small fish were captured in the SWOA channel than in the open water, indicating that larger individuals are typically using the SWOA channel.

Although very few listed species (i.e., delta smelt, steelhead, and Chinook salmon) were captured, the majority of them were captured within the restored SWOA floodplain or the created marsh plain habitats. The listed species were captured in 8 of the 14 sites sampled from 2002 to 2005, including Sites: 1A-3 (created marsh plain), 1A-4 (restored SWOA floodplain), 1A-6 (restored SWOA floodplain), 1A-7 (restored SWOA floodplain), 1A-10 (restored SWOA floodplain), 1B-2 (created marsh plain), 2-2 (created marsh plain), and 3-1 (open water).

Currently, the created and restored areas do not appear to be benefiting native species more than non-native species. In the Sacramento-San Joaquin Bay Delta, most resident fishes utilizing freshwater tidal wetlands are non-native (Brown 2003). Non-native species (e.g., inland silverside), as well as native species, appear to be benefiting from the restored SWOA and created marsh plain habitats. The created marsh plain may have greater potential for native species such as Sacramento splittail, based on higher abundance and CPUE for this species in the marsh plain areas. Although the SWOA habitat was not as heavily used by Sacramento splittail as the marsh plain terraces, rearing of juvenile Sacramento splittail in the SWOA increased in 2005.

The restored habitats of the Napa River FMP project area are still in the early stages of regeneration and have not yet become fully restored marshland. At this time, for native species, drawing conclusions about the effectiveness of the habitat alterations is premature. To draw stronger conclusions about restoration effectiveness efforts over the long term, further monitoring may be necessary.

Figure 5-1. Size distribution for striped bass by habitat type and gear type, 2002-2005, Napa River FMP.

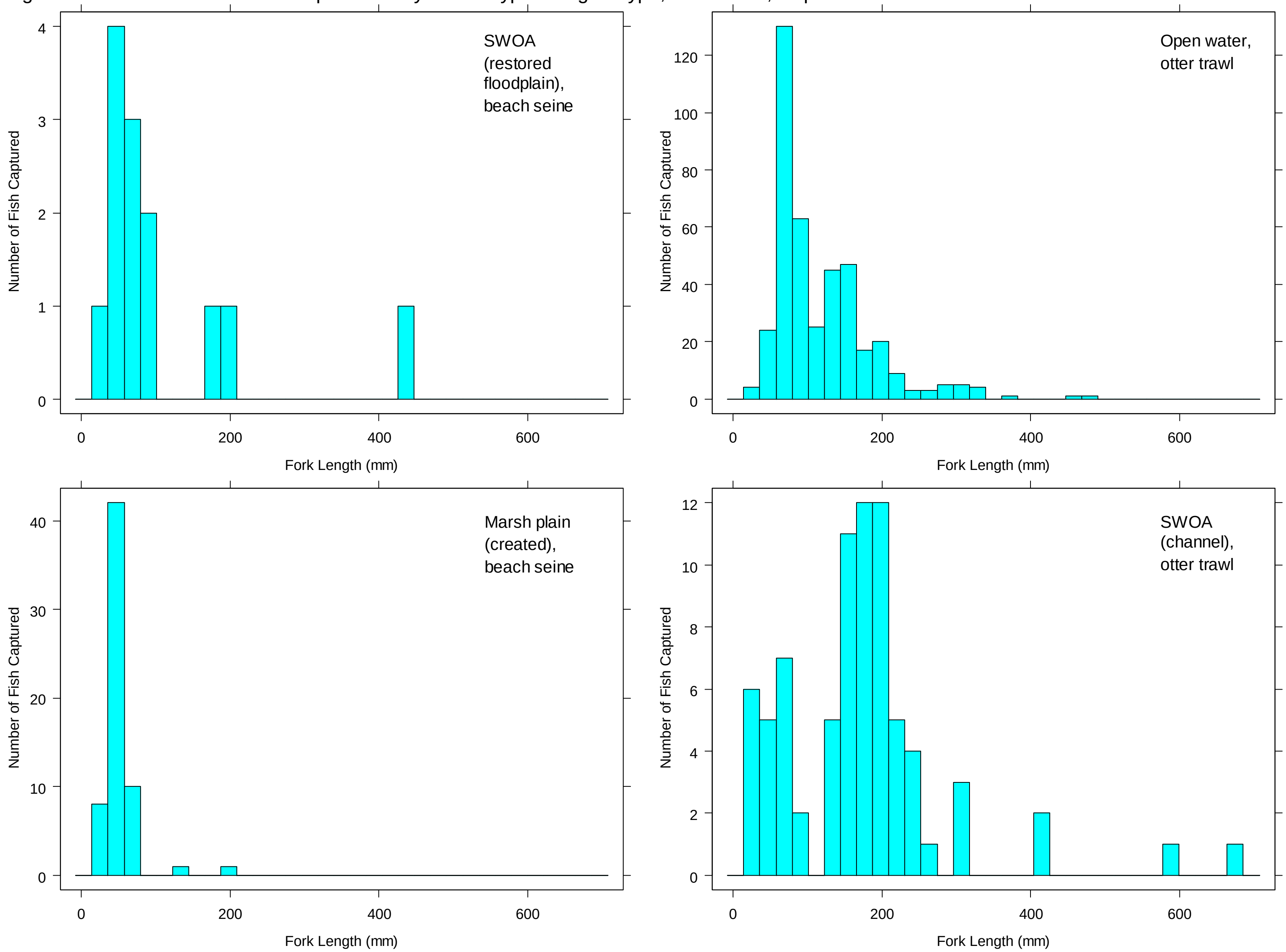
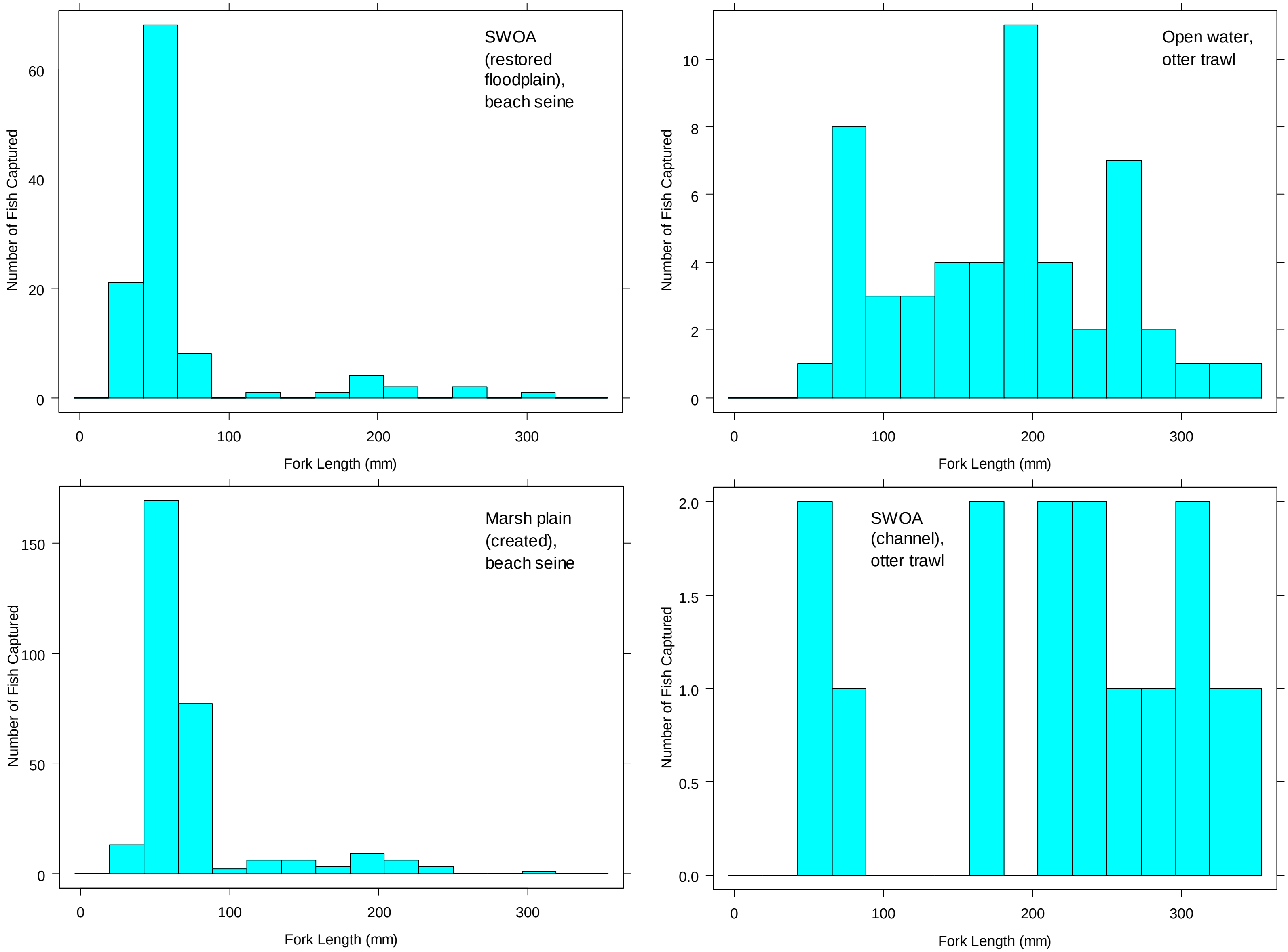


Figure 5-2. Size distribution for Sacramento splittail by habitat type and gear type, 2002-2005, Napa River FMP.



6 RECOMMENDATIONS

6.1 Monitoring Recommendations

Continued monitoring of fisheries and vegetation in the Project area is recommended. Surveys to date indicate that native and non-native fish species began to use the restored areas almost immediately following restoration of tidal inundation. Abundance of some native fish species, such as Sacramento splittail, has increased over the 5 year monitoring program, indicating that the Napa Project is having positive effects on fish numbers by either providing additional habitat for specific life stages or by potentially increasing production. However, several years of sampling were required to gather enough data to reveal initial trends. It is not possible to understand the full effects of the project on fish populations without continued monitoring, since restored habitat areas are still in a period of relatively rapid change, and fish populations lag in their response to these changes. Continued studies are recommended to determine the actual effects on fish populations following project completion.

In addition to the effects of the Napa Project, the ecosystem is not static. Non-native species are continually invading the San Francisco Bay ecosystem at a rate of 1 species every 14 weeks (CDFG 2001). The future effects of such introductions, as well as changes in environmental conditions, particularly associated with drought cycles, should be addressed by continuing certain aspects of the monitoring program.

Vegetation is very slowly returning to the restored SWOA. One of the recommendations from the CH2MHill vegetation surveys is that physical manipulation of some areas of the Napa Project may be required to enhance vegetation growth. Without additional vegetation monitoring, the status of vegetation will remain unknown. It will not be possible to determine when and where additional manipulation of habitat may be required for meeting stated goals without additional monitoring.

Monitoring efforts should be continued following completion of all flood control components on the Napa Project to determine if the Project goals are being met and to account for any lag time in effects. Monitoring should also continue until vegetation restoration and succession has proceeded further, and decisions regarding additional action towards attaining the goals and objectives can be made. At a minimum, a yearly sampling effort should be conducted to document species composition with changes in habitat as vegetation communities change. Photo points should be continued to document recovery of estuarine habitats. At a minimum, a reduced sampling effort, over the same time frame that this study occurred (potentially March, May, and June), should be conducted to continue to document habitat use by steelhead, Sacramento splittail, Chinook and chum salmon.

Year round future monitoring is recommended to continue to evaluate the sites and habitat sampled throughout the FMP field effort from 2001–2005. Data collected would improve the understanding of how fish use restored habitats during all seasons.

Although, if only limited funding was awarded, continued monitoring of all sites during March, April, and May is recommended.

Documenting the use of delta smelt in the project area is also of importance. The CDFG captured over 3,800 delta smelt larvae in 20-mm tow-net surveys in the Napa River/Project area in 2001 (USACE 2002). In contrast, only one adult delta smelt was captured by fyke net in the restored SWOA in 2002. Sampling of larval stages in restored and created habitats with larval light traps may help to identify early rearing areas, elucidate factors affecting survival of larval and juvenile fish in the project area, and help to understand the effects of environmental conditions/variables on their abundance and distribution; this type of approach is also suggested by Matern *et al.* (2002). Sampling between November and February with an otter trawl and purse seine may also increase catch of juvenile and adult delta smelt.

Sacramento splittail was removed from the federal listing in 2003, but because this species remains of special concern in California, continued monitoring is recommended. Clear genetic differences among splittail in the Napa, Petaluma, and Sacramento/San Joaquin River systems have been recently found (Melinda Baerwald and Bernie May, UCD, pers. comm., 2004). The Napa/Petaluma Sacramento splittail population is important because this unique population may contain different adaptive alleles of genes that could allow one population to survive an environmental change while another population (in a neighboring river) becomes extirpated (Melinda Baerwald and Bernie May, UCD, pers. comm., 2004). Continued monitoring of population abundance trends would be especially useful for the Napa/Petaluma population, given its smaller size and unique genetic makeup (Melinda Baerwald and Bernie May, UCD, pers. comm., 2004).

Few long-term monitoring efforts are being conducted in the lower Napa River and estuary at this time. Future pressures such as increased human population and water demands in the Napa River basin will require baseline and restoration success information to make future management decisions.

6.2 Restoration recommendations

The Napa Project presents a unique opportunity to learn about the effects of wetland and estuary restoration on fish and plant communities. The Napa Project can inform future estuarine and wetland restoration projects and improve designs and practices.

Sacramento sucker captured at restored Site 1A-3, May 2005.

Creating shallow water habitat, specifically marsh plain terraces, has provided additional flood relief and habitat for fish species. A strong association was found between the numbers of juvenile

Sacramento splittail and the created marsh plain terraces. These shallow water terraces may be providing both foraging opportunities and refuge habitat from larger predators found in the deep non-restored habitat.

To improve the restored SWOA, breaching additional levees between the Napa River and the SWOA is suggested. Breaching levees along the main river would provide better access for fish into the SWOA by allowing the fish to move directly from the Napa River to the SWOA, without having to go through the narrowly channeled Horseshoe Bend area where fish are likely to have an increased risk of predation by larger fish (i.e., striped bass). In addition, breaching additional levees near the SWOA is expected to provide better conditions for fish by increasing water circulation along the mud flats, increasing dissolved oxygen, and decreasing salinity.

Future habitat creation or restoration efforts should consider providing shallow water areas that remain inundated during low tide (stepped terraces). The created marsh plain terraces and restored SWOA completely dewater during low tide, requiring all fish to return to the deep non-restored open water habitat. Providing shallow habitat that remains inundated even during low tides may increase vegetation growth and create additional spawning habitat for native species (i.e., Sacramento splittail) and refuge for larval and juvenile life stages.

7 Program Team Members

The Napa River Fisheries Monitoring Program team members for 2005 are listed in Table 7-1.

Table 7-1. Napa River Fisheries Monitoring Program Team.

Name	Affiliation	Experience	Program Responsibility
Mike Dietl	Army Corps of Engineers	B.S. Fisheries Nine years experience in environmental management and fishery biology.	USACE Program Manager, Contracting Officer's Representative
Sharon Kramer	Stillwater Sciences	Ph.D. Marine Biology M.S. Zoology B.S. Aquatic Biology 29 years experience in marine, estuarine, and stream ecology in California and elsewhere.	Principal Investigator
Scott Wilcox	Stillwater Sciences	M.Ed. Natural Resources Management; B.S. Wildlife and Fisheries Biology. 26 years experience in fisheries and aquatic resource studies in California.	Project Manager
Steven Kramer	Stillwater Sciences	M.S. Natural Resources/Fisheries B.S. Fisheries Biology 29 years experience in marine, estuarine, and stream ecology.	Senior Fisheries Biologist
Lauren Dusek	Stillwater Sciences	B.S. Wildlife, Fish, and Conservation Biology. Five years of experience conducting fisheries studies in the Delta and tributary streams.	Deputy Project Manager and Field Leader
Peter Baker	Stillwater Sciences	Ph.D. Mathematics B.A. Mathematics 17 years of experience analyzing fisheries data.	Statistical Analysis
David Zajanc	Stillwater Sciences	B.S. Resource Management M.S. Fisheries Biology Seven years of statistical analysis experience.	Statistical Analysis
Donna Maniscalco	Jones and Stokes	B.S. Wildlife, Fish, and Conservation Biology Seven years conducting fisheries surveys of anadromous salmonids.	Field Biologist
Susan Davis	Jones and Stokes	M.A. English Literature B.A. English Literature Eight years of technical computer experience.	Web Developer
Michael McNabb	Jones and Stokes	B.S. Fisheries Three years of experience in programming and database development and 12 years experience in fisheries biology.	Fisheries Biologist/Programmer/ Database Developer
Johnson Wang	Consultant	Ph.D. Fisheries Over 30 years experience in larval fish studies.	Larval Fish Expert

8 Materials Purchase Report

No durable, capital expense items were purchased for the Napa River Fisheries Monitoring Program in 2005.

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Appendix A

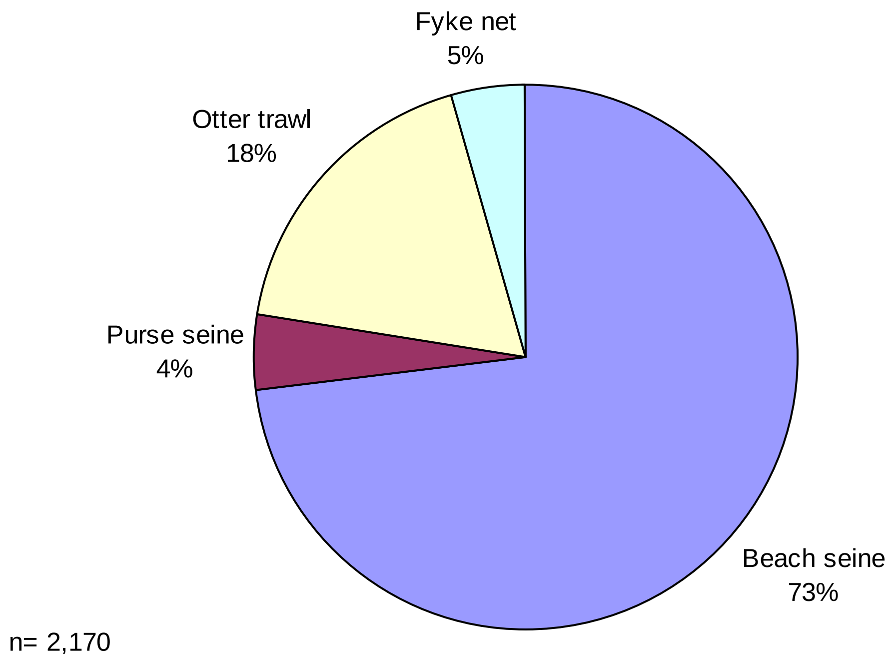


Figure A-1. Percent of juvenile and adult fish captured by gear type in the Napa River Project area in 2005.

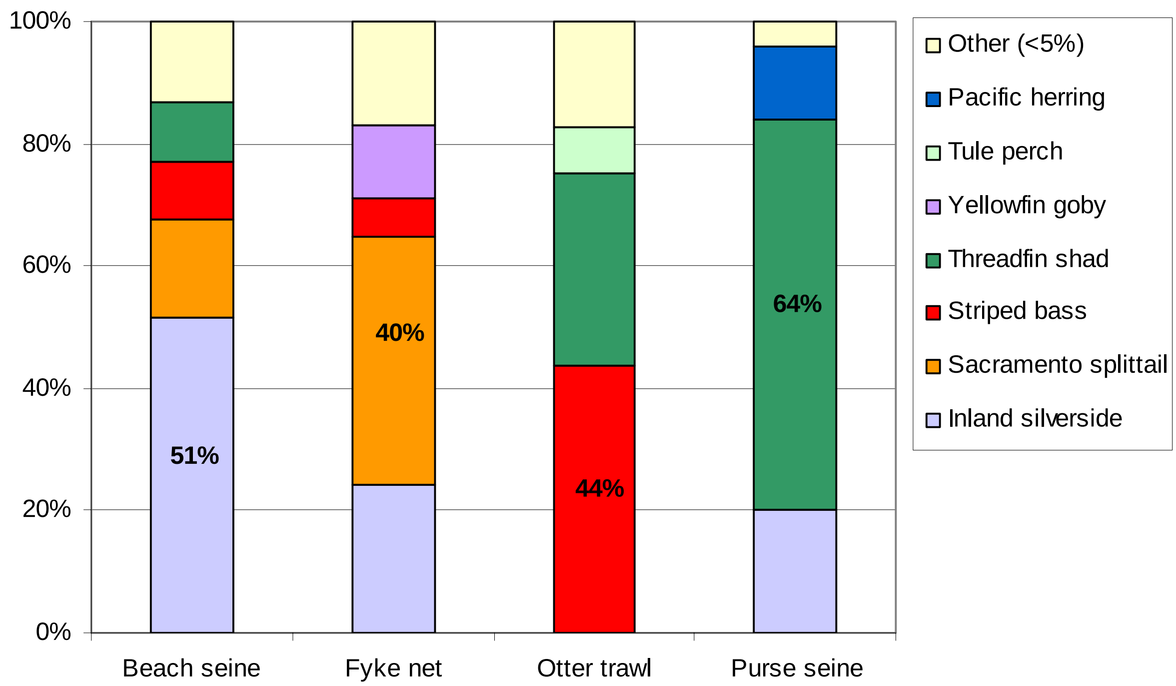


Figure A-2. Fish species composition by gear type in the Napa River Project area in 2005.

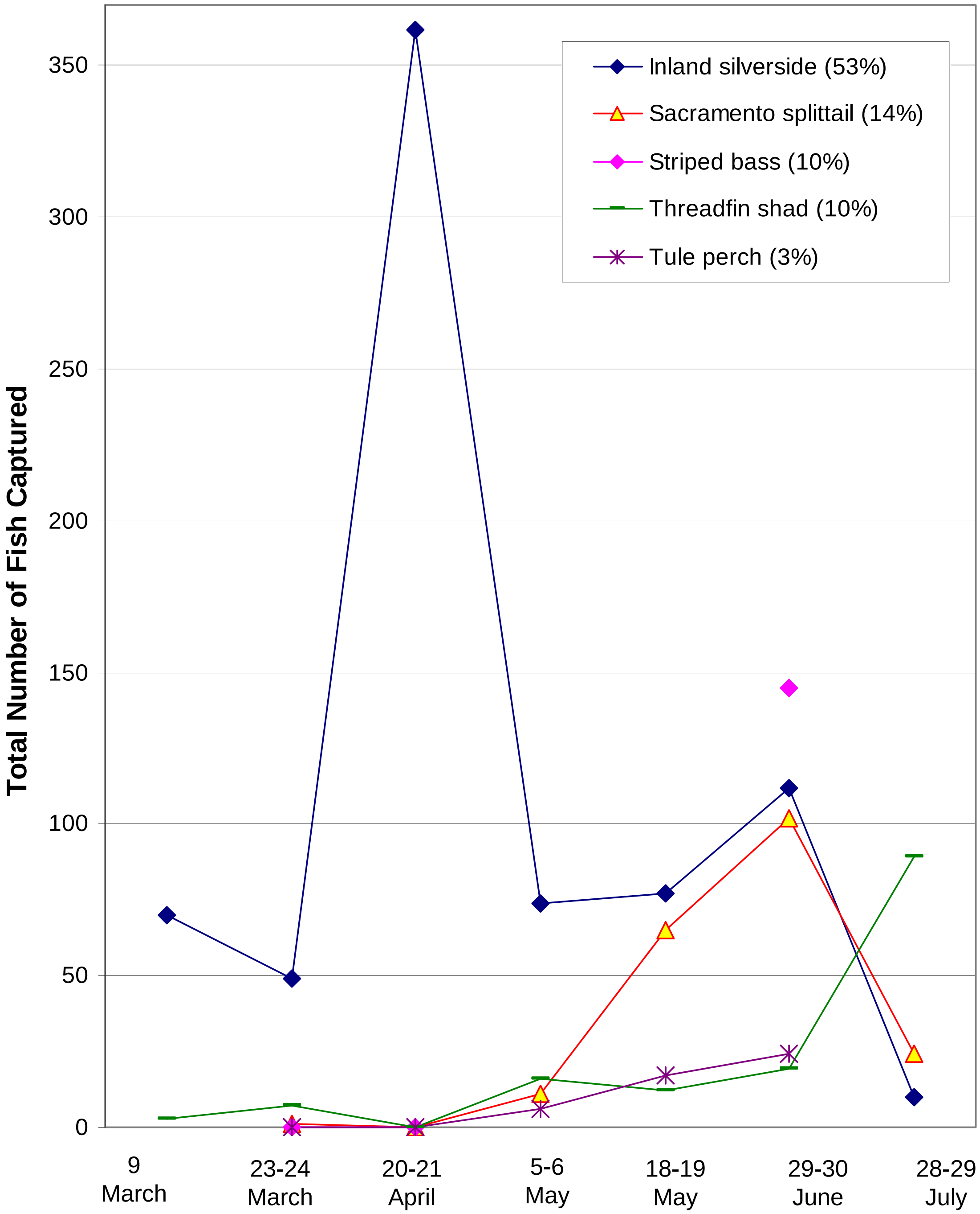


Figure A-3. Relative abundance of juvenile and adult fish species (>2% each of total catch) captured in the marsh plain terraces in 2005 in the Napa River Project area.

Fish species <2% each of catch (totaling 8% of total catch) include bluegill, carp, chum salmon, prickly sculpin, rainwater killifish, Sacramento sucker, shimofuri goby, staghorn sculpin, steelhead, yellowfin goby.

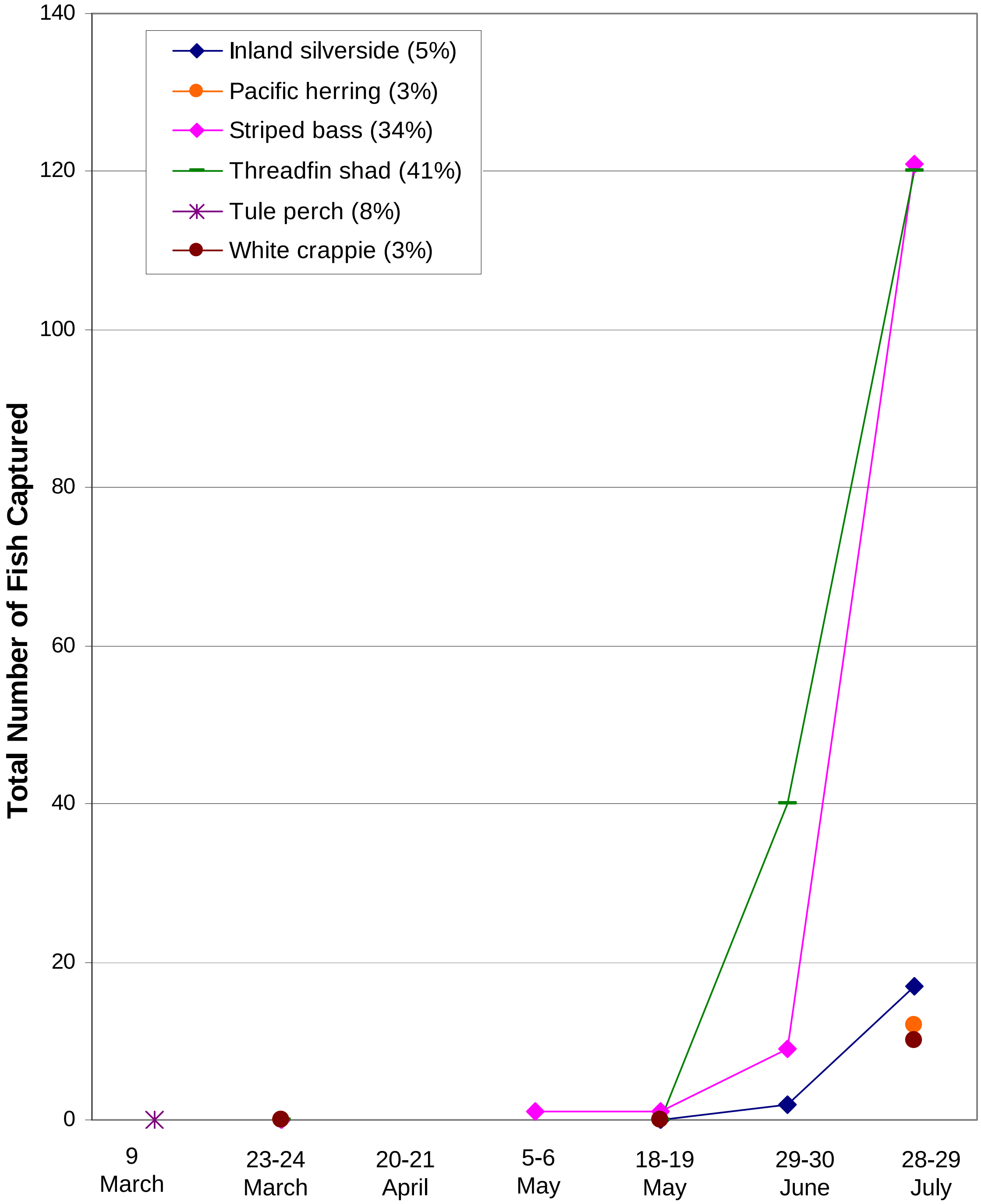


Figure A-4. Relative abundance of juvenile and adult fish species (>2% each of total catch) captured in the open water in 2005 in the Napa River Project area.

Fish species <2% each of catch (totaling 7% of total catch) include American shad, carp, chum salmon, prickly sculpin, Sacramento splittail, Sacramento sucker, shimofuri goby, staghorn sculpin, starry flounder, steelhead, yellowfin goby.

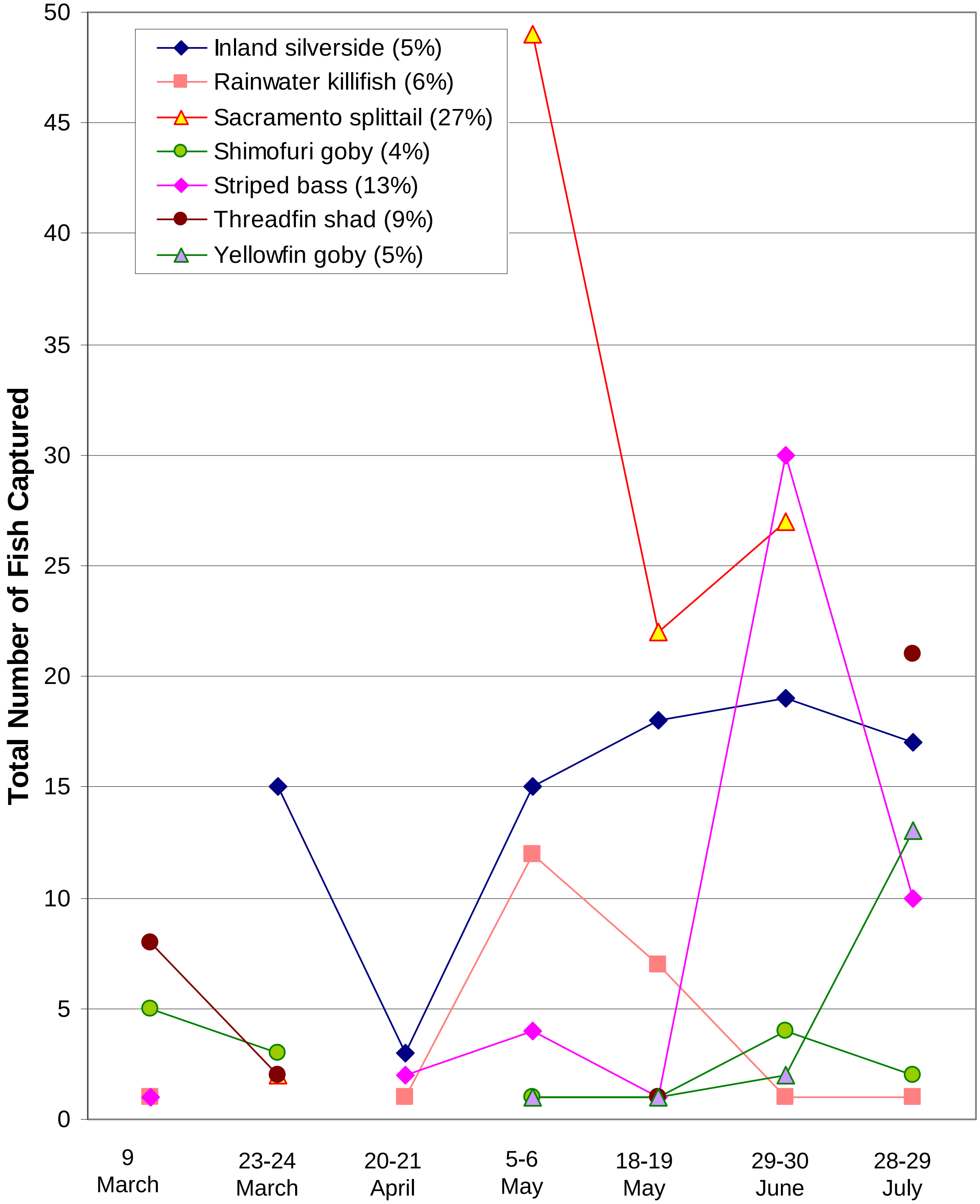


Figure A-5. Relative abundance of juvenile and adult fish species (>2% each of total catch) captured in the SWOA in 2005 in the Napa River Project area.

Fish species <2% each of catch (totaling 9% of total catch) include bluegill, chum salmon, long- jawed mudsucker, Pacific herring, prickly sculpin, steelhead, threespine stickleback, carp.

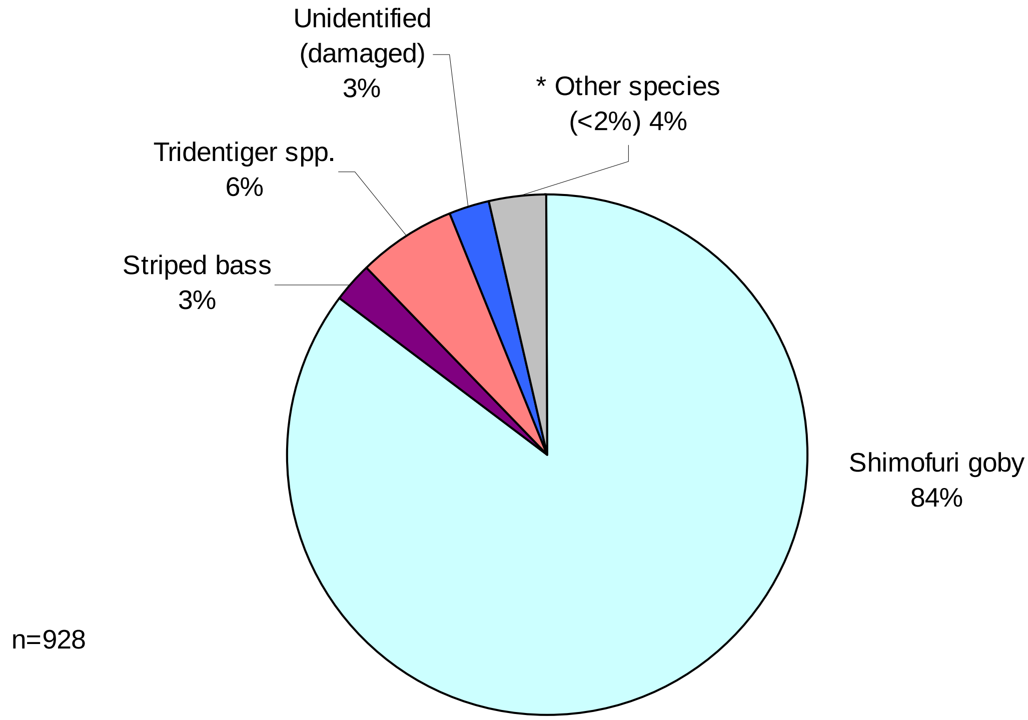


Figure A-6. Composition of larval fish by-catch in the Napa River Project area in 2005.
*Pacific herring (1.7%), threadfin shad (0.4%), yellowfin goby (0.8%), longfin smelt (0.6%).

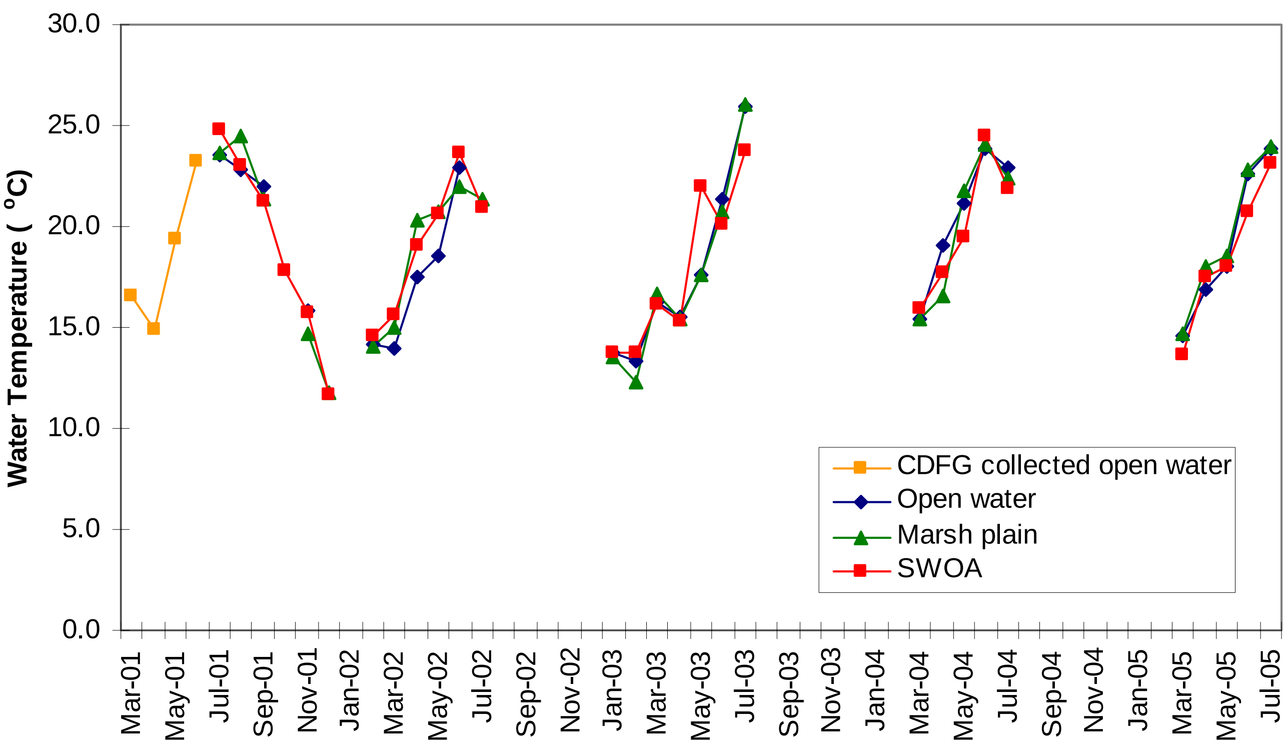


Figure A-7. Average water temperature in SWOA, marsh plain, and open water habitats in the Napa River Project area, at the time of sampling in 2001–2005.

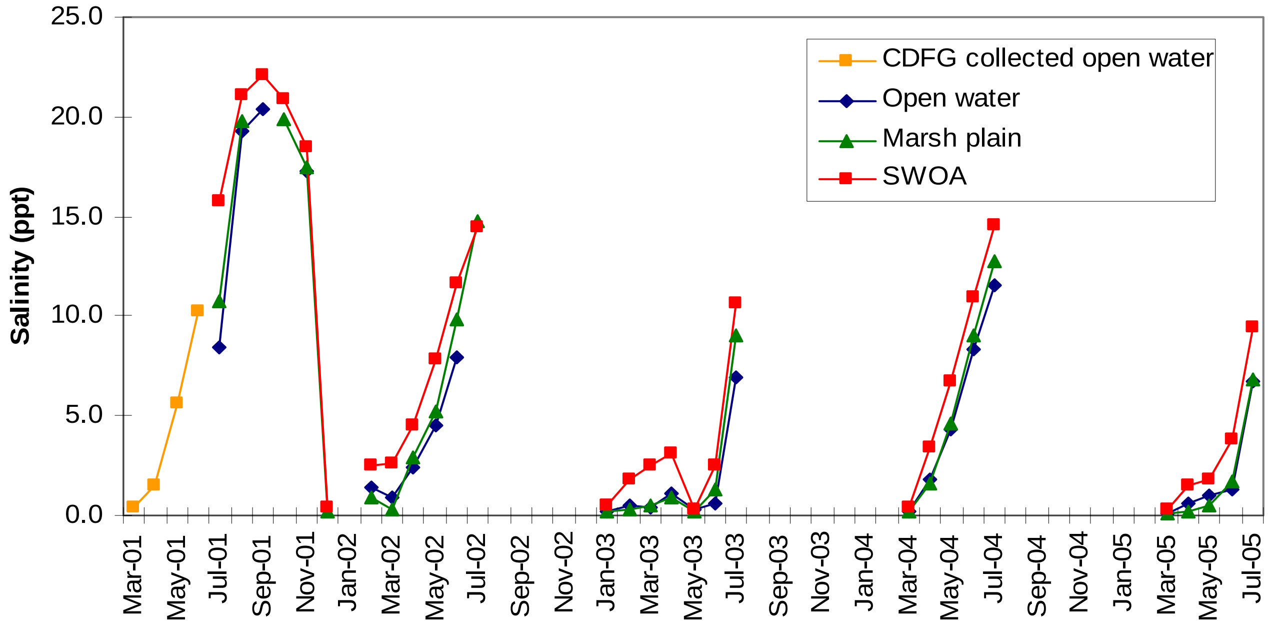


Figure A-8. Average salinity in SWOA, marsh plain, and open water habitats in the Napa River Project area, at the time of sampling in 2001–2005.

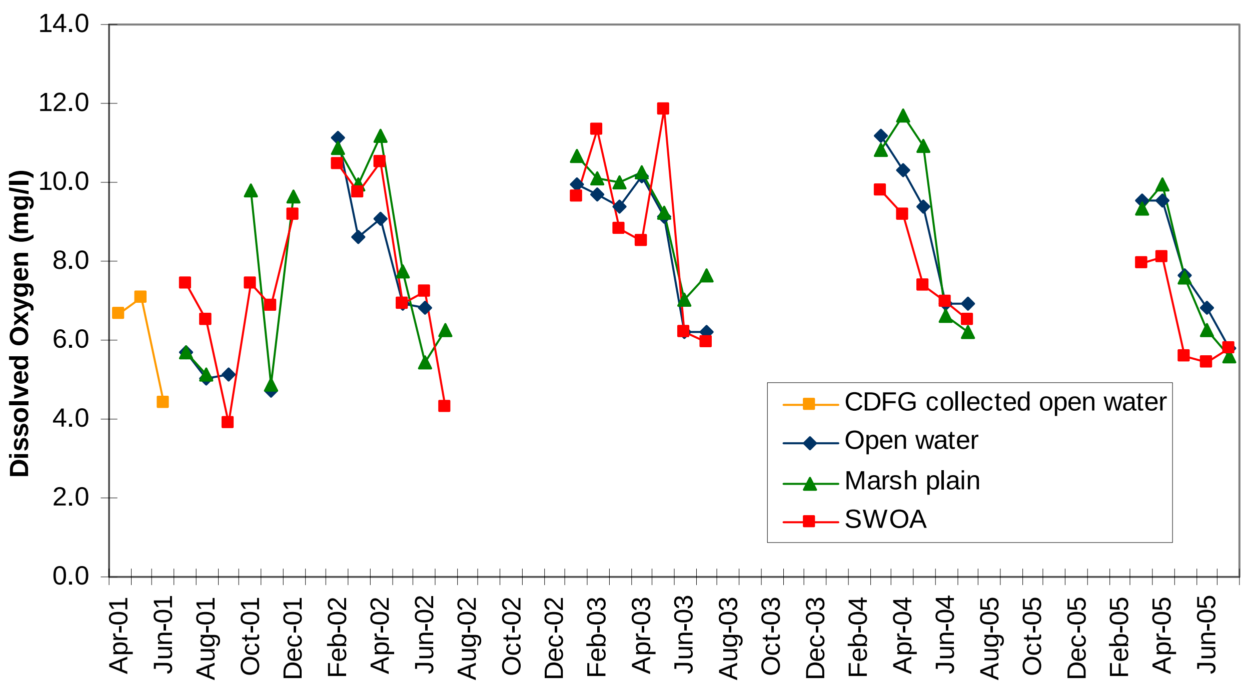


Figure A-9. Average dissolved oxygen in SWOA, marsh plain, and open water habitats in the Napa River Project area, at the time of sampling in 2001–2005.

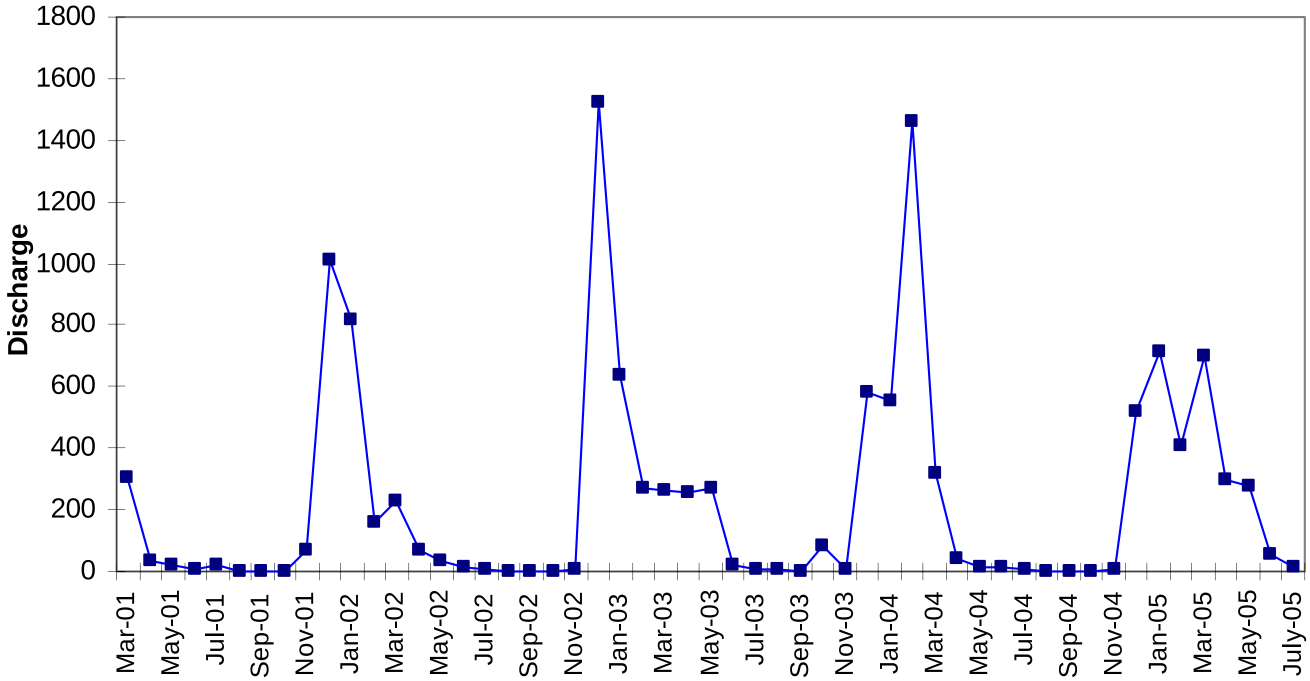
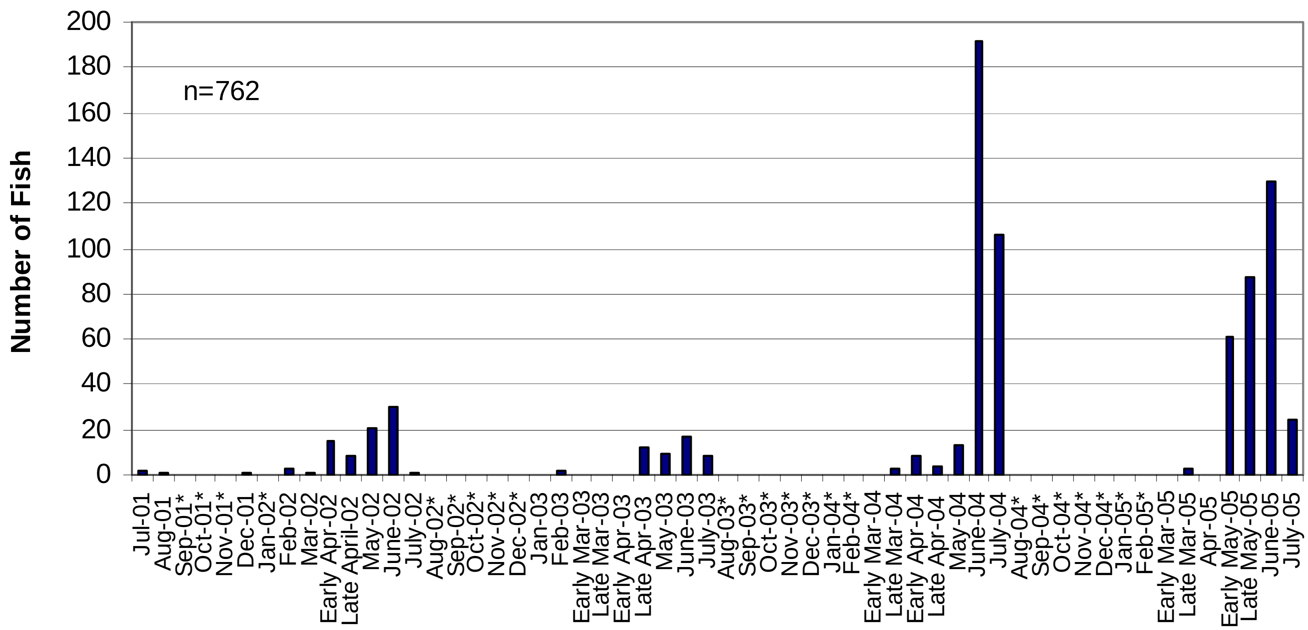
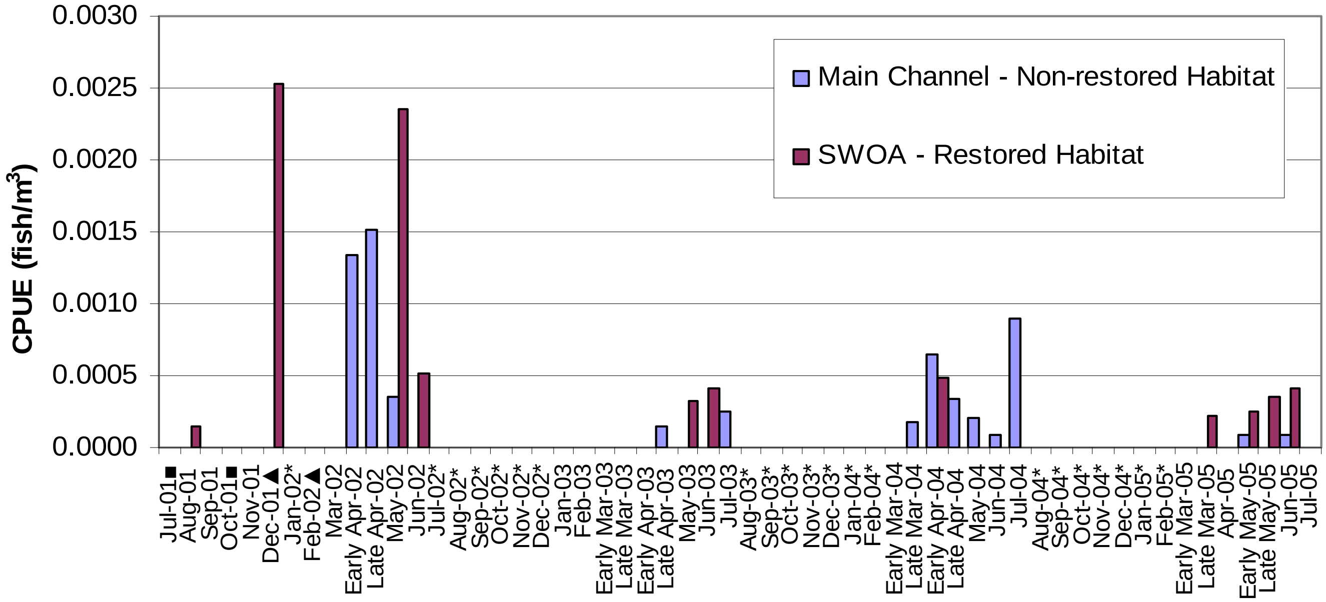


Figure A-10. Average monthly discharge in the Napa River (USGS gage #11458000), upstream of the project area, between March 2001 and July 2005.



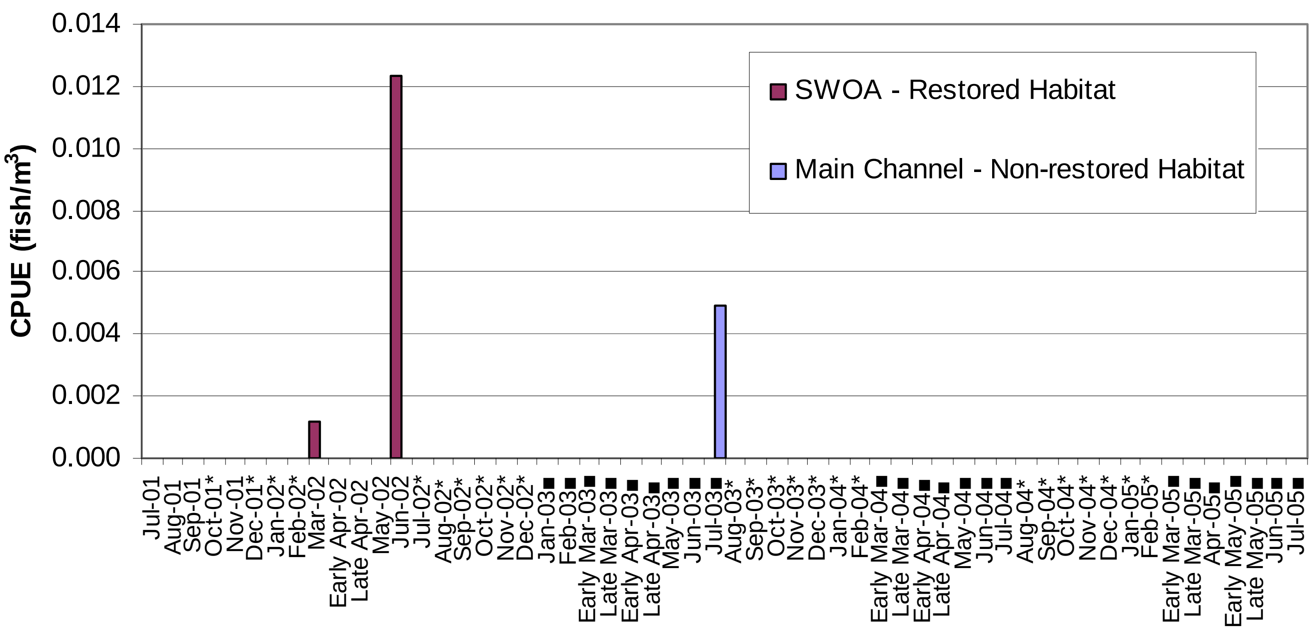
* No sampling occurred on this date.

Figure A-11. Total number of Sacramento splittail captured in the Napa River Project area, 2001–2005.



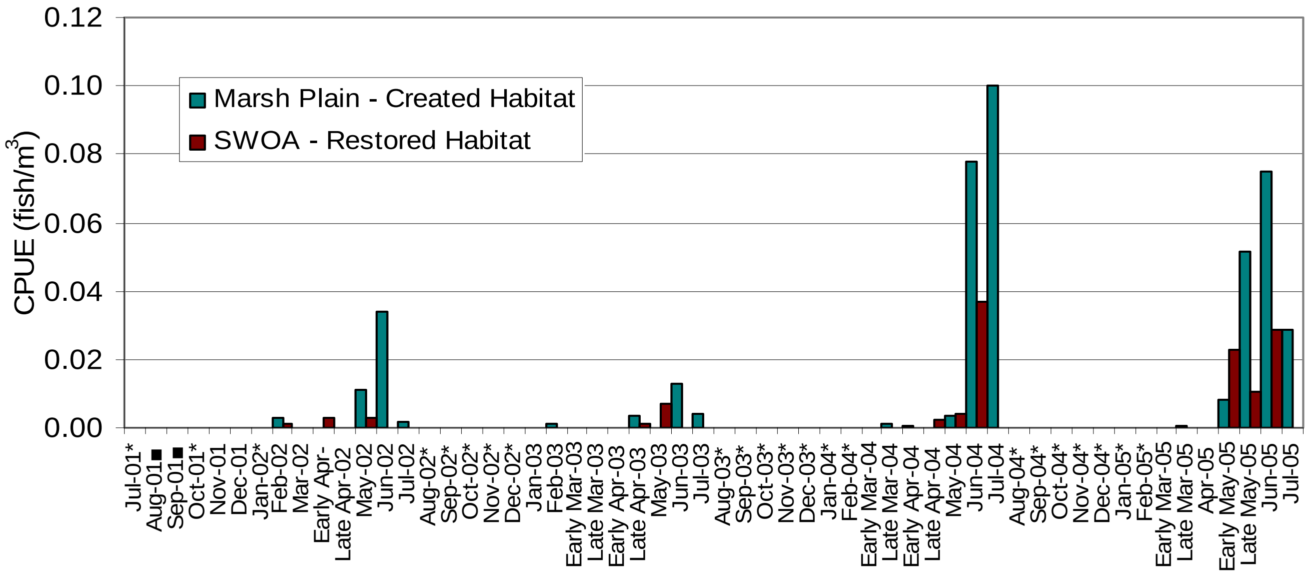
* No otter trawling occurred on this date.
■ Otter trawls were only deployed in the main channel on this date.
▲ Otter trawls were only deployed in the SWOA on this date.

Figure A-12. Catch per unit effort (CPUE) of Sacramento splittail captured in the otter trawl for main channel and SWOA habitats, 2001–2005.



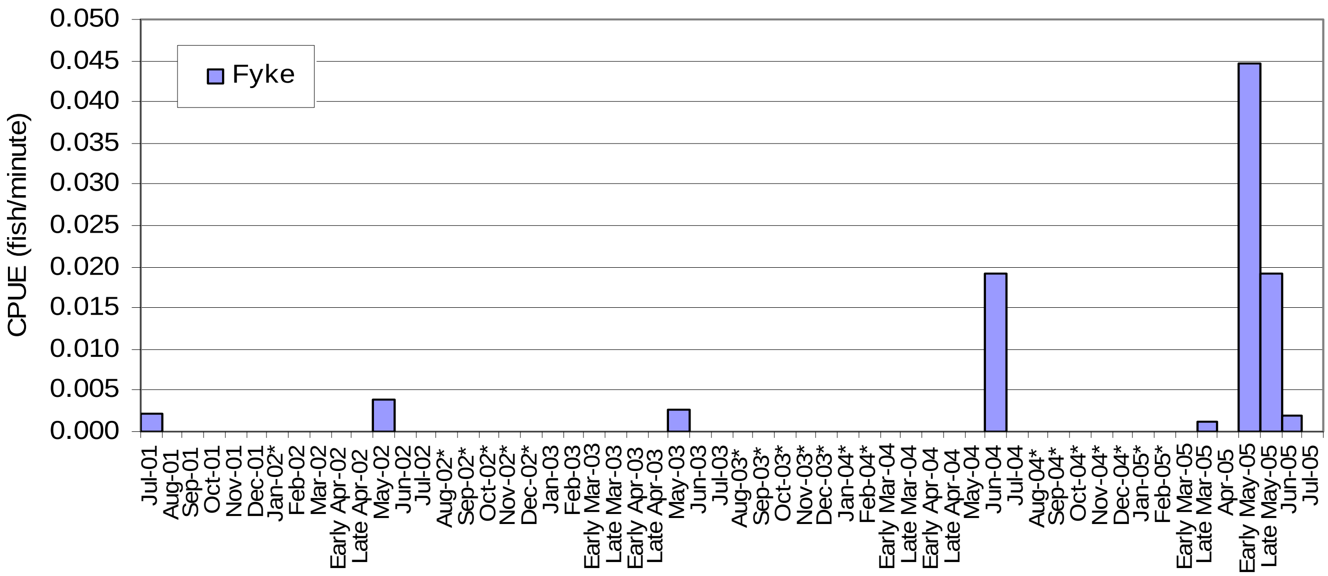
* No purse seining occurred on this date.
■ Purse seines were only deployed in the open water on this date.

Figure A-13. Catch per unit effort (CPUE) of Sacramento splittail in the purse seine for main channel and SWOA habitats, 2001–2005.



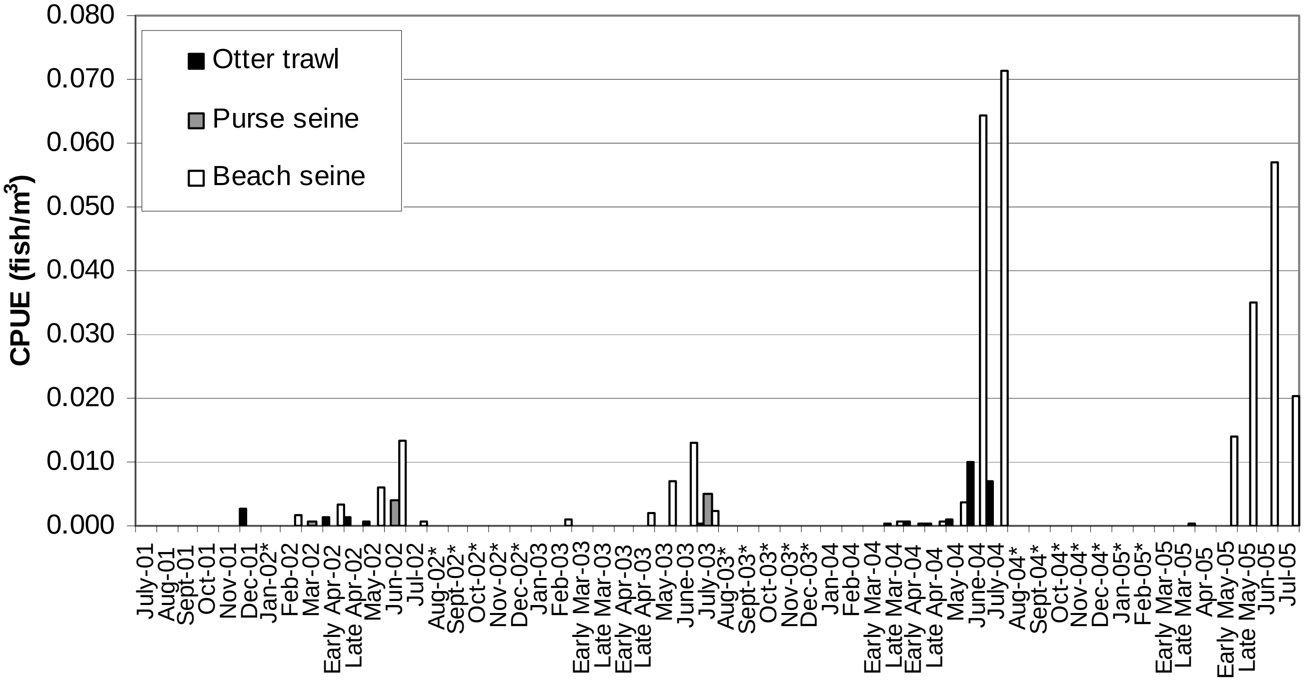
*   No beach seining occurred on this date.
■ Beach seines were only deployed at the SWOA on this date.

Figure A-14. Catch per unit effort (CPUE) of Sacramento splittail captured in the beach seine for marsh plain and SWOA habitats, 2001–2005.



* No sampling occurred on this date.
Two larval splittail were captured by a CDFG tow net in May 2001.

Figure A-15. Catch per unit effort (CPUE) (fish/minute) of Sacramento splittail captured in fyke nets in the Napa River Project area, 2001–2005.



* No sampling occurred on this date.

Figure A-16. Catch per unit effort (CPUE) (fish/m³) of Sacramento splittail by gear type in the Napa River Project area, 2001–2005.

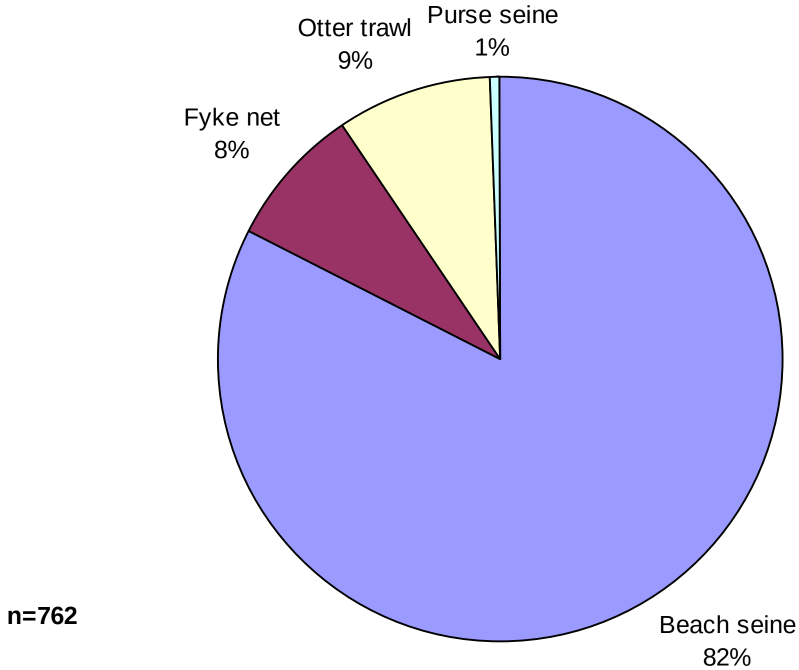


Figure A-17. Sacramento splittail captured by gear type in the Napa River Project area between July 2001–July 2002, January 2003–July 2003, March 2004–July 2004, and March 2005–July 2005.

Appendix B

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 07-16-01																																				
1A-2 Otter Trawl 1 of 2												1					1																			2
1A-9 Purse Seine 1 of 2																																				0
1A-9 Purse Seine 2 of 2																																				0
3-1 Otter Trawl 1 of 1																	1																			1
3-1 Purse Seine 1 of 2																																				0
3-1 Purse Seine 2 of 2																																				0
Date: 07-17-01																																				
1A-3 Fyke Net 1of 1																																				0
1A-5 Fyke Net 1 of 1																																				0
1A-6 Fyke Net 1 of 1							29																													29
1A-7 Fyke Net 1of 1							20										1																			21
1A-8 Fyke Net 1 of 1							81										3																			84
1A-10 Fyke Net 1 of 1							2																							2						4
July 2001 Subtotal	0	0	0	0	0	0	132	0	0	0	0	1	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	141
Date: 08-14-01																																				
1A-3 Fyke Net 1 of 1																																				0
1A-4 Beach Seine 1 of 2							48				0										2															50
1A-4 Beach Seine 2 of 2							24				1										1															26
1A-5 Fyke Net 1 of 1																																				0
1A-6 Fyke Net 1 of 1							21																													21
1A-7 Fyke Net 1 of 1							1										1																			2
1A-8 Fyke Net 1 of 1							33																													33
1A-10 Fyke Net 1 of 1																																				0
Date: 08-15-01																																				
1A-1 Otter Trawl 1 of 2												6											1									1			0	8
1A-1 Otter Trawl 2 of 2												10																				2			1	13
1A-2 Otter Trawl 1 of 2												2					5																		1	8
1A-2 Otter Trawl 2 of 2																	3																			3
1A-9 Purse Seine 1 of 2							146																													146
1A-9 Purse Seine 2 of 2																																				0
1B-1 Otter Trawl 1 of 2												15																				2			1	18
1B-1 Otter Trawl 2 of 2											1	26					1															1			1	30
2-1 Otter Trawl 1 of 2												5					1				1															7
2-1 Otter Trawl 2 of 2												14									3		1							1					1	20
3-1 Purse Seine 1 of 2							4																													4
3-1 Purse Seine 2 of 2							4																													4
August 2001 Subtotal	0	0	0	0	0	0	281	0	0	0	2	78	0	0	0	0	11	0	0	0	7	0	2	0	0	0	0	0	0	1	0	6	0	0	5	393
Date: 09-11-01																																				
1A-1 Otter Trawl 1 of 2												12													1		1					2				16
1A-1 Otter Trawl 2 of 2																																				0
1A-2 Otter Trawl 1 of 1											3																									3
1A-4 Beach Seine 1 of 2							49																													49
1A-4 Beach Seine 2 of 2							11				1																									12
1A-9 Purse Seine 1 of 2							1																													1
1A-9 Purse Seine 2 of 2																																				0
1B-1 Otter Trawl 1 of 2											1	46																							6	53
1B-1 Otter Trawl 2 of 2											4	1																								5
2-1 Otter Trawl 1 of 2												14																								14
2-1 Otter Trawl 2 of 2											1	16					1						1													19
3-1 Purse Seine 1 of 2							47																													47
3-1 Purse Seine 2 of 2	1						20																													21
September 2001 Subtotal	1	0	0	0	0	0	128	0	0	0	10	89	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	2	0	0	6	240

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																Native																			
Date: 10-11-01																																				
1A-3 Beach Seine 1 of 1							266																													266
1A-4 Beach Seine 1 of 3									5																											5
1A-4 Beach Seine 2 of 3							24		1																											25
1A-4 Beach Seine 3 of 3							94																													94
October 2001 Subtotal	0	0	0	0	0	0	384	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	390
Date: 11-08-01																																				
1A-1 Otter Trawl 1 of 2												4																							2	6
1A-1 Otter Trawl 2 of 2												2															2									4
1A-2 Otter Trawl 1 of 2												1																								1
1A-2 Otter Trawl 2 of 2												2																								2
1A-9 Purse Seine 1 of 2	3																																			3
1A-9 Purse Seine 2 of 2	1																																			1
1B-1 Otter Trawl 1 of 2												1																							6	7
1B-1 Otter Trawl 2 of 2												3																								3
2-1 Otter Trawl 1 of 3												5																							1	6
2-1 Otter Trawl 2 of 3	2											7		1																					1	11
2-1 Otter Trawl 3 of 3	1											7	1																						4	13
3-1 Purse Seine 1 of 2							180																													180
3-1 Purse Seine 2 of 2							88																													88
Date: 11-09-01																																				
1A-3 Fyke Net 1 of 1																																				0
1A-3 Beach Seine 1 of 1							621		1																											622
1A-4 Beach Seine 1 of 2							43																													43
1A-4 Beach Seine 2 of 2							26																													26
1A-5 Fyke Net 1 of 1																																				0
1A-6 Fyke Net 1 of 1	2						26				5																									33
1A-7 Fyke Net 1 of 1																																				0
1A-8 Fyke Net 1 of 1	1						4																													5
1A-10 Fyke Net 1 of 1							1				1																									2
November 2001 Subtotal	10	0	0	0	0	0	989	0	1	0	6	32	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	14	1,056
Date: 12-10-01																																				
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2											1	4																		1						6
1A-3 Beach Seine 1 of 1							225																													225
1A-4 (South End) Beach Seine 1 of 2				1			86															1														88
1A-4 (South End) Beach Seine 2 of 2							4																													4
1A-4 (North End) Beach Seine 1 of 2							5																													5
1A-4 (North End) Beach Seine 2 of 2							2																													2
December 2001 Subtotal	0	0	0	1	0	0	322		0	0	1	4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	330
July-December 2001 subtotal of juvenile and adult fish	11	0	0	1	0	0	2,236	0	7	0	19	204	1	1	0	0	18	0	0	0	7	1	3	0	1	0	3	0	0	4	0	8	0	0	25	2,550
Date: 02-25-02																																				
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2											4	1																								5
1A-3 Beach Seine 1 of 1							2																							1						3
1A-4 (South End) Beach Seine 1 of 2							1										5													1						7
1A-4 (South End) Beach Seine 2 of 2							7																													7
1A-4 (North End) Beach Seine 1 of 2							2																													2
1A-4 (North End) Beach Seine 2 of 2							6		1		2																			1						10
1B-1 Otter Trawl 1 of 1											1	3																								4
2-1 Otter Trawl 1 of 1																																				0
February 2002 Subtotal	0	0	0	0	0	0	18	0	1	0	7	4	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	38

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 03-25-02																																				
1A-1 Otter Trawl 1of 1																																				0
1A-2 Otter Trawl 1 of 2											2	2									1															5
1A-2 Otter Trawl 2 of 2											5	1																								6
1A-3 Beach Seine 1 of 1											2																18									20
1A-4 (South End) Beach Seine 1 of 2							5																				3									8
1A-4 (South End) Beach Seine 2 of 2				3			2				3	1	1											43			4									57
1A-4 (North End) Beach Seine 1 of 2											2																2							4		8
1A-4 (North End) Beach Seine 2 of 2							2																													2
1A-6 Fyke Net 1 of 1							1				1													14			1									17
1A-7 Fyke Net 1 of 1											1									1				2												4
1A-8 Fyke Net 1 of 1																					1			3										1		5
Date: 03-26-02																																				
1A-1 Otter Trawl 1 of 2					1						1	4																								6
1A-1 Otter Trawl 2 of 2																																				0
1A-9 Purse Seine 1 of 6							3						4											1			4									12
1A-9 Purse Seine 2 of 6																								1			2			1						4
1A-9 Purse Seine 3 of 6							2						2														2									6
1A-9 Purse Seine 4 of 6																																				0
1A-9 Purse Seine 5 of 6																																				0
1A-9 Purse Seine 6 of 6							1																													1
1A-10 Fyke Net 1 of 1																								59												59
1B-1 Otter Trawl 1 of 2																											3									3
1B-1 Otter Trawl 2 of 2											2	4									1						2									9
2-1 Otter Trawl 1 of 2																																			1	1
2-1 Otter Trawl 2 of 2		1										5																							1	7
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 3 of 3																																				0
March 2002 Subtotal	0	1	0	3	1	0	16	0	0	0	19	17	7	0	0	0	0	0	0	1	3	0	0	123	0	0	41	0	0	1	0	0	0	5	2	240
Date: 04-08-02																																				
1A-1 Otter Trawl 1 of 2											2	1															1			1						5
1A-1 Otter Trawl 2 of 2												1																		1						2
1A-4 (South End) Beach Seine 1 of 1							12																	92			1			3				2		110
1A-4 (North End) Beach Seine 1 of 3							7					2					1										30									40
1A-4 (North End) Beach Seine 2 of 3							6				1	2					2										37									48
1A-4 (North End) Beach Seine 3 of 3							5																	8			37			1						51
1A-6 Fyke Net 1 of 1							1																	11										2		14
1A-7 Fyke Net 1 of 1											1													294			1									296
1A-8 Fyke Net 1 of 1																																				0
1A-10 Fyke Net 1 of 1																								1,100												1,100
2-1 Otter Trawl 1 of 1											1													2												3
Date: 04-09-02																																				
1A-8 Fyke Net 1 of 1																								8												8
1A-9 Purse Seine 1 of 2																								23			1									24
1A-9 Purse Seine 2 of 2																																				0
1B-1 Otter Trawl 1 of 2											2	8															1			4						15
1B-1 Otter Trawl 2 of 2											8	6															1			4						19
2-1 Otter Trawl 1 of 3												4															1									5
2-1 Otter Trawl 2 of 3												3																								3
2-1 Otter Trawl 3 of 3											3	2																		1						6
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 3 of 3																																				0

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 04-22-02																																				
1A-3 Beach Seine 1 of 2							2										1							2			49									54
1A-3 Beach Seine 2 of 2							2																				18							2		22
1A-4 (South End) Beach Seine 1 of 2							11				1							1						1			3							10		27
1A-4 (South End) Beach Seine 2 of 2							17										2							3			11							24		57
1A-4 (North End) Beach Seine 1 of 2							1																	6			6							1		14
1A-4 (North End) Beach Seine 2 of 2							1				2													2			8							1		14
1A-6 Fyke Net 1 of 1							1																				5							1		7
1A-7 Fyke Net 1 of 1																								7			8									15
1A-8 Fyke Net 1 of 1																								150			19									169
Date: 04-23-02																																				
1A-1 Otter Trawl 1 of 1												3															4									7
1A-2 Otter Trawl 1 of 1											2	2																								4
1A-9 Purse Seine 1 of 2																																				0
1A-9 Purse Seine 2 of 2																								5			5									10
1A-10 Fyke Net 1 of 1																								1,491												1,491
1B-1 Otter Trawl 1 of 2											2	8															1			2						13
1B-1 Otter Trawl 2 of 2											2	18					1										1			3						25
2-1 Otter Trawl 1 of 2											1	8																		2						11
2-1 Otter Trawl 2 of 2	1																													1						2
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3													2																							2
3-1 Purse Seine 3 of 3																																				0
April 2002 Subtotal	1	0	0	0	0	0	66	0	0	0	28	68	2	0	0	0	7	1	0	0	0	0	0	3,205	0	0	249	0	0	23	0	0	0	43	0	3,693
Date: 05-22-02																																				
1A-1 Otter Trawl 1 of 2																														1						1
1A-1 Otter Trawl 2 of 2																																				0
1A-2 Otter Trawl 1 of 2												2																		2						4
1A-2 Otter Trawl 2 of 2				1								1																		1						3
1A-6 Fyke Net 1 of 1																																				0
1A-7 Fyke Net 1 of 1							6										6																	3		15
1A-8 Fyke Net 1 of 1							34										1									1	2			1						39
1A-10 Fyke Net 1 of 1							5				1	1					2							10			1			2						22
1B-1 Otter Trawl 1 of 2											1	2															2									5
1B-1 Otter Trawl 2 of 2											1	5													1		1									8
2-1 Otter Trawl 1 of 3																									3		1									4
2-1 Otter Trawl 2 of 3												2																								2
2-1 Otter Trawl 3 of 3																														1						1
Date: 05-23-02																																				
1A-3 Beach Seine 1 of 2							1				3																9			8						21
1A-3 Beach Seine 2 of 2							5				1						8										59			1					1	75
1A-4 (South End) Beach Seine 1 of 3																																				0
1A-4 (South End) Beach Seine 2 of 3																														3						3
1A-4 (South End) Beach Seine 3 of 3							1																				1									2
1A-4 (North End) Beach Seine 1 of 3											1						2									3										6
1A-4 (North End) Beach Seine 2 of 3											1						5									4	2									12
1A-4 (North End) Beach Seine 3 of 3											2						5													1						8
1A-9 Purse Seine 1 of 2												1																								1
1A-9 Purse Seine 2 of 2							2																													2
3-1 Purse Seine 1 of 3													2																				1			3
3-1 Purse Seine 2 of 3							1																													1
3-1 Purse Seine 3 of 3							6						3					1																1		11
May 2002 Subtotal	0	0	0	1	0	0	61	0	0	0	11	14	5	0	0	0	29	1	0	0	0	0	0	10	4	8	78	0	0	21	0	0	1	4	1	249

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	**Native**																		
Date: 06-20-02																																				
1A-3 Beach Seine 1 of 3											12						2													3						17
1A-3 Beach Seine 2 of 3						1					11						8										1			19					2	42
1A-3 Beach Seine 3 of 3						1	4				2						4										1			5				2		19
1A-4 (South End) Beach Seine 1 of 2							1				1																									2
1A-4 (South End) Beach Seine 2 of 2																	1																			1
1A-4 (North End) Beach Seine 1 of 2							5																													5
1A-4 (North End) Beach Seine 2 of 2							4				2																									6
1A-4 (West Side) Beach Seine 1 of 1							6				2						2																			10
1A-6 Fyke Net 1 of 1																											1									1
1A-7 Fyke Net 1 of 1							3				2						2																			7
1A-8 Fyke Net 1 of 1							11				1						1																			13
1A-10 Fyke Net 1 of 1							8										1																			9
Date: 06-21-02																																				
1A-1 Otter Trawl 1of 2																																				0
1A-1 Otter Trawl 2 of 2												1																								1
1A-2 Otter Trawl 1 of 2												1																		1						2
1A-2 Otter Trawl 2 of 2											1																									1
1A-9 Purse Seine 1 of 3																														2						2
1A-9 Purse Seine 2 of 3																																				0
1A-9 Purse Seine 3 of 3																																				0
1B-1 Otter Trawl 1 of 2																																				0
1B-1 Otter Trawl 2 of 2																																				0
2-1 Otter Trawl 1 of 2												5																								5
2-1 Otter Trawl 2 of 2												6																								6
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3													2																							2
3-1 Purse Seine 3 of 3							3						1																							4
June 2002 Subtotal	0	0	0	0	0	2	45	0	0	0	34	13	3	0	0	0	21	0	0	0	0	0	0	0	0	0	3	0	0	30	0	0	0	2	2	155
Date: 07-19-02																																				
1A-3 Beach Seine 1 of 2							6				3						16																			25
1A-3 Beach Seine 2 of 2							5				20						10										1			1						37
1A-4 (South End) Beach Seine 1 of 2							1				1																									2
1A-4 (South End) Beach Seine 2 of 2							4																													4
1A-4 (North End) Beach Seine 1 of 2																																				0
1A-4 (North End) Beach Seine 2 of 2																																				0
July 2002 Subtotal	0	0	0	0	0	0	16	0	0	0	24	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	68
February-July 2002 subtotal of juvenile and adult fish	1	1	0	4	1	2	222	0	1	0	123	116	17	0	0	0	88	2	0	1	3	0	0	3,338	4	8	372	0	0	79	0	0	1	54	5	4,443

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																	
Date: 01-29-03																																			
1A-4 (North End) Beach Seine 1 of 5																																			0
1A-4 (North End) Beach Seine 2 of 5																																			0
1A-4 (North End) Beach Seine 3 of 5																																			0
1A-4 (South End) Beach Seine 4 of 5							1																												1
1A-4 (South End) Beach Seine 5 of 5																																			0
3-1 Purse Seine 1 of 2																																			0
3-1 Purse Seine 2 of 2																																			0
2-1 Otter Trawl 1 of 2																																			0
2-1 Otter Trawl 2 of 2																																			0
1B-1 Otter Trawl 1 of 3																																			0
1B-1 Otter Trawl 2 of 3																																			0
1B-1 Otter Trawl 3 of 3																																			0
1A-1 Otter Trawl 1 of 2																																			0
1A-1 Otter Trawl 2 of 2												1																							1
1A-2 Otter Trawl 1 of 2											1																								1
1A-2 Otter Trawl 2 of 2											9																								9
Date: 01-31-03																																			
1A-3 Beach Seine 1 of 3							1				1																				1					3
1A-3 Beach Seine 2 of 3							20	1																							3					24
1A-3 Beach Seine 3 of 3							7																												7
2-2 Beach Seine 1 of 3																																			0
2-2 Beach Seine 2 of 3																																			0
2-2 Beach Seine 3 of 3																																			0
January 2003 Subtotal	0	0	0	0	0	0	29	1	0	0	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	46
Date: 02-26-03																																			
3-1 Purse Seine 1 of 3																																			0
3-1 Purse Seine 2 of 3																																			0
3-1 Purse Seine 3 of 3																																			0
2-1 Otter Trawl 1 of 2																																			0
2-1 Otter Trawl 2 of 2																																			0
1B-1 Otter Trawl 1 of 2																															1					1
1B-1 Otter Trawl 2 of 2																																			0
1A-1 Otter Trawl 1 of 2																																			0
1A-1 Otter Trawl 2 of 2													1																						1
1A-2 Otter Trawl 1 of 2											5																								5
1A-2 Otter Trawl 2 of 2											1																								1
Date: 02-27-03																																			
1A-4 (North End) Beach Seine 1 of 4																																			0
1A-4 (North End) Beach Seine 2 of 4																																			0
1A-4 (South End) Beach Seine 3 of 4																																			0
1A-4 (South End) Beach Seine 4 of 4																																			0
1A-3 Beach Seine 1 of 3																														1	1					2
1A-3 Beach Seine 2 of 3																												1		1						2
1A-3 Beach Seine 3 of 3																												1								1
2-2 Beach Seine 1 of 3							8																												8
2-2 Beach Seine 2 of 3																																			0
2-2 Beach Seine 3 of 3							129																												129
February 2003 Subtotal	0	0	0	0	0	0	137	0	0	0	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	0	0	0	0	150

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	**Native**																		
Date: 03-13-03																																				
3-1 Purse Seine 1 of 2																																				0
3-1 Purse Seine 2 of 2																																				0
2-1 Otter Trawl 1 of 2												2																								2
2-1 Otter Trawl 2 of 2																																			4	4
1B-1 Otter Trawl 1 of 2																															1	1			1	3
1B-1 Otter Trawl 2 of 2												1																								1
1A-1 Otter Trawl 1 of 2											2				1																	2				5
1A-1 Otter Trawl 2 of 2										1	4						2															4				11
1A-2 Otter Trawl 1 of 2													2															2							1	5
1A-2 Otter Trawl 2 of 2											1		1															1								3
1A-4 (North End) Beach Seine 1 of 6							4																													4
1A-4 (North End) Beach Seine 2 of 6							5																													5
1A-4 (North End) Beach Seine 3 of 6							2				1																							1		4
1A-4 (South End) Beach Seine 4 of 6							1																													1
1A-4 (South End) Beach Seine 5 of 6							1																													1
1A-4 (South End) Beach Seine 6 of 6							1																													1
1A-3 Beach Seine 1 of 2							6																													6
1A-3 Beach Seine 2 of 2							2																								2					4
1A-6 Fyke net																																				0
1A-7 Fyke net							6				2																									8
1A-10 Fyke net																																				0
Date: 03-27-03																																				
1A-3 Beach Seine 1 of 2							2																													2
1A-3 Beach Seine 2 of 2							23				2																	1			1					27
1A-4 (North End) Beach Seine 1 of 4							4				10						1											5								20
1A-4 (North End) Beach Seine 2 of 4							4																													4
1A-4 (South End) Beach Seine 3 of 4							20																													20
1A-4 (South End) Beach Seine 4 of 4							1																													1
1A-6 Fyke net																																				0
1A-7 Fyke net																												1								1
1A-10 Fyke net																																				0
Date: 03-28-03																																				
3-1 Purse Seine 1 of 2																												1								1
3-1 Purse Seine 2 of 2																																				0
2-1 Otter Trawl 1 of 2				1							2		2																						2	7
2-1 Otter Trawl 2 of 2											2																								1	3
1B-1 Otter Trawl 1 of 2																																				0
1B-1 Otter Trawl 2 of 2											1																									1
1A-1 Otter Trawl 1 of 2													1											1												2
1A-1 Otter Trawl 2 of 2			1								2																								2	5
1A-2 Otter Trawl 1 of 2																																				0
1A-2 Otter Trawl 2 of 2											1																									1
March 2003 Subtotal	0	0	1	1	0	0	82	0	0	1	30	3	6	0	1	0	3	0	0	0	0	0	0	1	0	0	0	11	0	0	4	7	0	1	11	163

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																			
Date: 04-10-03																																				
3-1 Purse Seine 1 of 2																																				0
3-1 Purse Seine 2 of 2																																				0
2-1 Otter Trawl 1 of 3																												1								1
2-1 Otter Trawl 2 of 3											1		2															1								4
2-1 Otter Trawl 3 of 3																																				0
1B-1 Otter Trawl 1 of 2											1													27												28
1B-1 Otter Trawl 2 of 2	1										1													114								1				117
1A-1 Otter Trawl 1 of 2																								1												1
1A-1 Otter Trawl 2 of 2																																				0
1A-2 Otter Trawl 1 of 2											1																	19								20
1A-2 Otter Trawl 2 of 2											2																	4								6
Date: 04-11-03																																				
1A-3 Beach Seine 1 of 2							4																					2			1					7
1A-3 Beach Seine 2 of 2							1																													1
1A-4 (North End) Beach Seine 1 of 4							5				6																									11
1A-4 (North End) Beach Seine 2 of 4							1				5																	1								7
1A-4 (South End) Beach Seine 3 of 4							6																													6
1A-4 (South End) Beach Seine 4 of 4							5			1														3										1		10
1A-6 Fyke net										1																		2								3
1A-7 Fyke net																																				0
1A-10 Fyke net																																		1		1
Date: 04-24-03																																				
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 3 of 3																																				0
2-1 Otter Trawl 1 of 2											3		3															5								11
2-1 Otter Trawl 2 of 2											2																					1				3
1B-1 Otter Trawl 1 of 2											1																	1				1				3
1B-1 Otter Trawl 2 of 2											1																				1					2
1A-1 Otter Trawl 1 of 2																														1						1
1A-1 Otter Trawl 2 of 2																								10						1						11
1A-2 Otter Trawl 1 of 2																								6				1								7
1A-2 Otter Trawl 2 of 2												1												21				3								25
Date: 04-25-03																																				
1A-3 Beach Seine 1 of 4							1																	2												3
1A-3 Beach Seine 2 of 4							3																					1		3						7
1A-3 Beach Seine 3 of 4							11																					2		2						15
1A-3 Beach Seine 4 of 4							5																							3	1					9
1A-4 Beach Seine 1 of 5											1													2						1						4
1A-4 Beach Seine 2 of 5																								13						1						14
1A-4 Beach Seine 3 of 5											1																									1
1A-4 Beach Seine 4 of 5																								6												6
1A-4 Beach Seine 5 of 5							1																	6												7
1A-6 Fyke net																								294												294
1A-7 Fyke net																								125												125
1A-10 Fyke net																								16												16
April 2003 subtotal	1	0	0	0	0	0	43	0	0	2	26	1	5	0	0	0	0	0	0	0	0	0	0	646	0	0	0	43	0	12	3	3	0	2	0	787

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 05-13-03																																				
1A-3 Beach Seine 1 of 2											8																	3			1	6				18
1A-3 Beach Seine 2 of 2							2				11						1											16		4		8			1	43
1A-4 Beach Seine 1 of 4							1				4						5											3								13
1A-4 Beach Seine 2 of 4											7																	1								8
1A-4 Beach Seine 3 of 4																												1		2						3
1A-4 Beach Seine 4 of 4							1				5		2																		1					9
1A-6 Fyke net											2																	1								3
1A-7 Fyke net											1							1												1						3
1A-10 Fyke net											1																	1								2
3-1 Purse Seine 1 of 2																																				0
3-1 Purse Seine 2 of 2							13																													13
2-1 Otter Trawl 1 of 2																																				0
2-1 Otter Trawl 2 of 2																																				0
Date: 05-14-03																																				
1B-1 Otter Trawl 1 of 2																																1				1
1B-1 Otter Trawl 2 of 2																																				0
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2																																				0
1A-2 Otter Trawl 1 of 2																														1						1
1A-2 Otter Trawl 2 of 2																	3													1						4
May 2003 subtotal	0	0	0	0	0	0	17	0	0	0	39	0	2	0	0	0	9	1	0	0	0	0	0	0	0	0	0	26	0	9	2	15	0	0	1	121
Date: 06-07-03																																				
1A-4 Beach Seine 1 of 4							2				5						3											3								13
1A-4 Beach Seine 2 of 4							6				13						7											3								29
1A-4 Beach Seine 3 of 4				1			15				2																									18
1A-4 Beach Seine 4 of 4							1																													1
1A-6 Fyke net																	2											1								3
1A-7 Fyke net							2																													2
1A-10 Fyke net							1																													1
3-1 Purse Seine 1 of 2																																				0
3-1 Purse Seine 2 of 2																																				0
2-1 Otter Trawl 1 of 2																																				0
2-1 Otter Trawl 2 of 2																																				0
Date: 06-08-03																																				
1B-1 Otter Trawl 1 of 2																												1								1
1B-1 Otter Trawl 2 of 2																																				0
1A-1 Otter Trawl 1 of 2																																1				1
1A-1 Otter Trawl 2 of 2																												1								1
1A-2 Otter Trawl 1 of 2				1																										2						3
1A-2 Otter Trawl 2 of 2				1							3	2					2											1		1						10
2-1 Otter Trawl 1 of 2												6																								6
2-1 Otter Trawl 2 of 2												4																								4
1A-3 Beach Seine 1 of 2												1																1		11	2	6		2	2	25
1A-3 Beach Seine 2 of 2							2				11						9											1		3	3	14				43
June 2003 subtotal	0	0	0	3	0	0	29	0	0	0	34	13	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	12	0	17	5	21	0	2	2	161

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 07-23-03																																				
1A-4 Beach Seine 1 of 4							2				3																									5
1A-4 Beach Seine 2 of 4							2				6																									8
1A-4 Beach Seine 3 of 4							5				19						3																			27
1A-4 Beach Seine 4 of 4							9				62	2	3				3																			79
1A-3 Beach Seine 1 of 2											30	5					4											1				3		1		44
1A-3 Beach Seine 2 of 2									1		12	27	579				2													3		2		8		634
1A-6 Fyke net											5						1																			6
1A-7 Fyke net							40				6	1	1				7																		1	56
1A-10 Fyke net							8				11	4					6																		1	30
3-1 Purse Seine 1 of 2							1						33																	1					4	39
3-1 Purse Seine 2 of 2							2						14																						1	17
1A-2 Otter Trawl 1 of 2				1							21		9																							31
1A-2 Otter Trawl 2 of 2											17	1	1																							19
2-1 Otter Trawl 1 of 1		3									1	1	10															1							1	17
Date: 07-24-03																																				
1B-1 Otter Trawl 1 of 2		21									1	36	43											1						2						104
1B-1 Otter Trawl 2 of 2		7									1	27	1															1		1						38
1A-1 Otter Trawl 1 of 2		1																										1								2
1A-1 Otter Trawl 2 of 2																	1													1						2
2-1 Otter Trawl 1 of 2		53										163	84																						4	304
2-1 Otter Trawl 2 of 2		16										5	11																							32
July 2003 subtotal	0	101	0	1	0	0	69	0	1	0	195	272	789	0	0	0	27	0	0	0	0	0	0	1	0	0	0	4	0	8	0	5	0	9	12	1,494
Total juvenile and adult fish in 2003	1	101	1	5	0	0	406	1	1	3	341	290	803	0	1	0	62	1	0	0	0	0	0	648	0	0	0	98	0	48	20	51	0	14	26	2,922
Date: 03-3-04																																				
1A-3 Beach Seine 1 of 3											1																									1
1A-3 Beach Seine 2 of 3							1				1																									2
1A-3 Beach Seine 3 of 3																																				0
1A-6 Fyke net																																				0
1A-7 Fyke net																																				0
1A-10 Fyke net																																				0
3-1 Purse Seine 1 of 2																																				0
3-1 Purse Seine 2 of 2																																				0
2-2 Beach Seine 1 of 2							8																								1					9
2-2 Beach Seine 2 of 2							20																													20
Date: 03-4-04																																				
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2																																1				1
1A-2 Otter Trawl 1 of 2	2										1																									3
1A-2 Otter Trawl 2 of 2											1																									1
2-1 Otter Trawl 1 of 3																																			1	1
2-1 Otter Trawl 2 of 3																																				0
2-1 Otter Trawl 3 of 3																																				0
1B-1 Otter Trawl 1 of 2																																				0
1B-1 Otter Trawl 2 of 2																																				0
1B-2 Beach Seine 1 of 3																																				0
1B-2 Beach Seine 2 of 3							6																													6
1B-2 Beach Seine 3 of 3							22																													22
1A-4 Beach Seine 1 of 4							1																													1
1A-4 Beach Seine 2 of 4																																				0
1A-4 Beach Seine 3 of 4							1																													1
1A-4 Beach Seine 4 of 4							1																													1

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 03-17-04																																				
1A-4 Beach Seine 1 of 4							2				2																									4
1A-4 Beach Seine 2 of 4				1			2																													3
1A-4 Beach Seine 3 of 4							2				2		3																							7
1A-4 Beach Seine 4 of 4							20												1																	21
1A-6 Fyke net							2				1		1																							4
1A-7 Fyke net																																				0
1A-10 Fyke net							2											1															1			4
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 2 of 3																																				0
1B-2 Beach Seine 1 of 2							6				2																									8
1B-2 Beach Seine 2 of 2							30																													30
Date: 03-18-04																																				
1A-1 Otter Trawl 1 of 2												2																		1		4			1	8
1A-1 Otter Trawl 2 of 2																																				0
1A-2 Otter Trawl 1 of 2											2	4																								6
1A-2 Otter Trawl 2 of 2				1							5	1																								7
2-1 Otter Trawl 1 of 2																																			1	1
2-1 Otter Trawl 2 of 2												1																							1	2
1B-1 Otter Trawl 1 of 2												1																			2	3			1	7
1B-1 Otter Trawl 2 of 2																																1			1	2
2-2 Beach Seine 1 of 2							9																													9
2-2 Beach Seine 2 of 2							33																								1			1		35
1A-3 Beach Seine 1 of 2							23																													23
1A-3 Beach Seine 2 of 2							1						2																	2					1	6
March 2004 subtotal	2	0	0	2	0	0	192	0	0	0	18	9	6	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	4	9	1	1	7	256
Date: 04-15-04																																				
1A-1 Otter Trawl 1 of 2																								2								1				3
1A-1 Otter Trawl 2 of 2											1	4															3			1		3			1	13
1A-2 Otter Trawl 1 of 2	1			2							2	7																								12
1A-2 Otter Trawl 2 of 2	1			6							2	1																		1						11
1B-1 Otter Trawl 1 of 2												1													1					2						4
1B-1 Otter Trawl 2 of 2																																				0
3-1 Purse Seine 1 of 2							1												4														1			6
3-1 Purse Seine 2 of 2																			2																	2
2-2 Beach Seine 1 of 2							48																													48
2-2 Beach Seine 2 of 2							364																													364
2-1 Otter Trawl 1 of 3	1			1								5	1																	1		2			5	16
2-1 Otter Trawl 2 of 3												3																			1				1	5
2-1 Otter Trawl 3 of 3	1											2	1																	2					2	8
Date: 04-16-04																																				
1B-2 Beach Seine 1 of 2							40						7																	1						48
1B-2 Beach Seine 2 of 2							46						17																							63
1A-4 Beach Seine 1 of 5							101																													101
1A-4 Beach Seine 2 of 5							10																											1		11
1A-4 Beach Seine 3 of 5							8																													8
1A-4 Beach Seine 4 of 5							4					1	3												1											9
1A-4 Beach Seine 5 of 5											1																									1
1A-6 Fyke net	1						4			1	1													4												11
1A-7 Fyke net							25																	1												26
1A-10 Fyke net							6																	3										2		11
1A-3 Beach Seine 1 of 2							2						9																							11
1A-3 Beach Seine 2 of 2							9						26																							35

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 04-29-04																																				
1A-4 Beach Seine 1 of 4							7			2	1														1											11
1A-4 Beach Seine 2 of 4							15																													15
1A-4 Beach Seine 3 of 4							7				3	1																								11
1A-4 Beach Seine 4 of 4							8			3							2													1						14
1A-6 Fyke net							1												1																	2
1A-7 Fyke net				1			9																											1		11
1A-10 Fyke net																																		1		1
2-2 Beach Seine 1 of 2							62																												1	63
2-2 Beach Seine 2 of 2							83				1																								2	86
1B-2 Beach Seine 1 of 2							36				1																							1		38
1B-2 Beach Seine 2 of 2							43																													43
1A-3 Beach Seine 1 of 2							16						3														1								2	22
1A-3 Beach Seine 2 of 2							10						1														1									12
Date: 04-30-04																																				
1A-1 Otter Trawl 1 of 2												2																				2				4
1A-1 Otter Trawl 2 of 2																								1												1
1A-2 Otter Trawl 1 of 2											1	7																								8
1A-2 Otter Trawl 2 of 2				1								2																								3
2-1 Otter Trawl 1 of 2											1																									1
2-1 Otter Trawl 2 of 2	1										3	6																				2				12
1B-1 Otter Trawl 1 of 2		1										2													1					3		1				8
1B-1 Otter Trawl 2 of 2												1																								1
3-1 Purse Seine 1 of 2							6																													6
3-1 Purse Seine 2 of 2							16																													16
April 2004 subtotal	6	1	0	11	0	0	987	0	0	6	18	45	68	0	0	0	2	0	7	0	0	0	0	11	4	0	5	0	0	12	1	11	1	6	14	1,216
Date: 05-13-04																																				
1A-4 Beach Seine 1 of 4				1			2				1																			1						5
1A-4 Beach Seine 2 of 4							4																													4
1A-4 Beach Seine 3 of 4							5				1																			1						7
1A-4 Beach Seine 4 of 4										1																				2						3
1A-6 Fyke net							1																	10												11
1A-7 Fyke net							1																	1												2
1A-10 Fyke net							2			1																										3
1A-1 Otter Trawl 1 of 2												1												7						2						10
1A-1 Otter Trawl 2 of 2																																1				1
1A-3 Beach Seine 1 of 2							3					1	1				1										11			1		3			1	22
1A-3 Beach Seine 2 of 2							23																				1			1		1				26
1A-2 Otter Trawl 1 of 2																																				0
1A-2 Otter Trawl 2 of 2				1								5												1												7
Date: 05-14-04																																				
2-2 Beach Seine 1 of 2							105				4		1				2												1	2					23	138
2-2 Beach Seine 2 of 2						1	98						1																						3	103
2-1 Otter Trawl 1 of 2		1										1	1																							3
2-1 Otter Trawl 2 of 2		3										5	1																							9
1B-1 Otter Trawl 1 of 2				1								4																			1					6
1B-1 Otter Trawl 2 of 2				2								5																								7
3-1 Purse Seine 1 of 3	9												3																							12
3-1 Purse Seine 2 of 3	5												2																							7
3-1 Purse Seine 3 of 3	5												2																							7
1B-2 Beach Seine 1 of 2							13				1		45																1	3					1	64
1B-2 Beach Seine 2 of 2							93				2		29																							124
May 2004 subtotal	19	4	0	5	0	1	350	0	0	2	9	22	86	0	0	0	3	0	0	0	0	0	0	19	0	0	12	0	2	13	1	5	0	0	28	581

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 06-15-04																																				
1A-4 Beach Seine 1 of 3							9				14						2													30						55
1A-4 Beach Seine 2 of 3							2																													2
1A-4 Beach Seine 3 of 3							3																							3						6
1A-6 Fyke net											3						1																			4
1A-7 Fyke net							26																							2						28
1A-10 Fyke net							2				3						3													15						23
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2																																				0
1B-1 Otter Trawl 1 of 3							1																													1
1B-1 Otter Trawl 2 of 3				1																																1
1B-1 Otter Trawl 3 of 3																																				0
1A-2 Otter Trawl 1 of 2												3																								3
1A-2 Otter Trawl 2 of 2												2																								2
2-1 Otter Trawl 1 of 3												1																		1						2
2-1 Otter Trawl 2 of 3	2																																			2
2-1 Otter Trawl 3 of 3													2																							2
Date: 06-16-04																																				
1A-3 Beach Seine 1 of 2							17	1		1	5	1					1										1			63		1			2	93
1A-3 Beach Seine 2 of 2							31										1													4						36
2-2 Beach Seine 1 of 2				1			12					14	1				4													19					10	61
2-2 Beach Seine 2 of 2				8			23					8																		13				1	5	58
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3							3																													3
3-1 Purse Seine 3 of 3	3						4																													7
1B-2 Beach Seine 1 of 2							6				4	1					15										1			30					3	60
1B-2 Beach Seine 2 of 2				1			3	1					4				11													12					3	35
June 2004 subtotal	5	0	0	11	0	0	142	2	0	1	29	30	7	0	0	0	38	0	0	0	0	0	0	0	0	0	2	0	0	192	0	1	0	1	23	484
Date: 07-12-04																																				
1A-4 Beach Seine 1 of 4							4																													4
1A-4 Beach Seine 2 of 4											6						1																			7
1A-4 Beach Seine 3 of 4																																				0
1A-4 Beach Seine 4 of 4							3			2																										5
1A-6 Fyke net											2						1																			3
1A-7 Fyke net							133																													133
1A-10 Fyke net							1				4						7																			12
1A-1 Otter Trawl 1 of 2												4																								4
1A-1 Otter Trawl 2 of 2																																				0
1B-1 Otter Trawl 1 of 2	1																																			1
1B-1 Otter Trawl 2 of 2												2																							1	3
1A-2 Otter Trawl 1 of 2												4																								4
1A-2 Otter Trawl 2 of 2												1																								1
2-1 Otter Trawl 1 of 2																														6						6
2-1 Otter Trawl 2 of 2												5	1																	3					1	10
1A-3 Beach Seine 1 of 2							1	1			4						5													38						49
1A-3 Beach Seine 2 of 2							2										9													13						24
Date: 07-13-04																																				
2-2 Beach Seine 1 of 2							2					2					3													1						8
2-2 Beach Seine 2 of 2							5				1	4																		8						18
3-1 Purse Seine 1 of 3													5																1							6
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 3 of 3																																				0
1B-2 Beach Seine 1 of 2																														3						3
1B-2 Beach Seine 2 of 2							3										1													34						38
July 2004 subtotal	1	0	0	0	0	0	154	1	0	2	17	22	6	0	0	0	27	0	0	0	0	0	0	0	0	0	0	0	1	106	0	0	0	0	2	339
Total juvenile and adult fish in 2004	33	5	0	29	0	1	1,825	3	0	11	91	128	173	0	0	0	70	1	8	0	0	0	0	30	4	0	19	0	3	326	6	26	2	8	74	2,876

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	Native																		
Date: 03-9-05																																				
1A-4 Beach Seine 1 of 4																																				0
1A-4 Beach Seine 2 of 4											3																1									4
1A-4 Beach Seine 3 of 4																																				0
1A-4 Beach Seine 4 of 4																																		1		1
1A-6 Fyke net																																				0
1A-7 Fyke net																																				0
1A-10 Fyke net										1																	1									2
1A-1 Otter Trawl 1 of 2											1																									1
1A-1 Otter Trawl 2 of 2																																				0
1B-2 Beach Seine 1 of 2			1				9																													10
1B-2 Beach Seine 2 of 2							13																													13
1A-2 Otter Trawl 1 of 3				3								1	1																							5
1A-2 Otter Trawl 2 of 3																																				0
1A-2 Otter Trawl 3 of 3											2		7																							9
2-1 Otter Trawl 1 of 2																																				0
2-1 Otter Trawl 2 of 2																																				0
2-2 Beach Seine 1 of 2							3																													3
2-2 Beach Seine 2 of 2							45																													45
1A-3 Beach Seine 1 of 3													3						1								1									5
1A-3 Beach Seine 2 of 3																																				0
1A-3 Beach Seine 3 of 3																																				0
Date: 03-10-05																																				
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 3 of 3																																				0
1B-1 Beach Seine 1 of 2																																				0
1B-1 Beach Seine 2 of 2																																				0
Date: 03-23-05																																				
1A-4 Beach Seine 1 of 4													1														1									2
1A-4 Beach Seine 2 of 4																																				0
1A-4 Beach Seine 3 of 4							8												1																	9
1A-4 Beach Seine 4 of 4			1				2																													3
1A-6 Fyke net																					1												1			2
1A-7 Fyke net																																				0
1A-10 Fyke net							5												1											1						7
1A-1 Otter Trawl 1 of 3																																				0
1A-1 Otter Trawl 2 of 3																																				0
1A-1 Otter Trawl 3 of 3																																				0
1B-2 Beach Seine 1 of 2											1																									1
1B-2 Beach Seine 2 of 2							2				2																									4
1A-2 Otter Trawl 1 of 2																																				0
1A-2 Otter Trawl 2 of 2											3		1																	1						5
1B-1 Beach Seine 1 of 2																																				0
1B-1 Beach Seine 2 of 2											1																									1
1A-3 Beach Seine 1 of 3							3						1						2																	6
1A-3 Beach Seine 2 of 3							4						6						1																	11
1A-3 Beach Seine 3 of 3							2																							1						3
Date: 03-24-05																																				
3-1 Purse Seine 1 of 3																			1																	1
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 3 of 3																																				0
2-1 Otter Trawl 1 of 2																																				0
2-1 Otter Trawl 2 of 2																																				0
2-2 Beach Seine 1 of 2							29				4								3																	36
2-2 Beach Seine 2 of 2							9				3								1																	13
March 2005 subtotal	0	0	2	3	0	0	134	0	0	1	20	1	20	0	0	0	0	0	11	0	1	0	0	0	0	0	4	0	0	3	0	0	1	1	0	202

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																Native																			
Date: 04-20-05																																				
1A-6 Fyke net																																				0
1A-7 Fyke net																																		1		1
1A-10 Fyke net			2																1																	3
1A-4 Beach Seine 1 of 4																																				0
1A-4 Beach Seine 2 of 4																																				0
1A-4 Beach Seine 3 of 4				1			1			1																										3
1A-4 Beach Seine 4 of 4				1			2																													3
1A-3 Beach Seine 1 of 2							19																				2									21
1A-3 Beach Seine 2 of 2							1				1																1									3
2-2 Beach Seine 1 of 2							66												1								1				1					69
2-2 Beach Seine 2 of 2				3			227												2																	232
1A-2 Otter Trawl 1 of 2												1																								1
1A-2 Otter Trawl 2 of 2												1																								1
2-1 Otter Trawl 1 of 2											1																									1
2-1 Otter Trawl 2 of 2																																				0
3-1 Purse Seine 1 of 3																																				0
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 3 of 3																																				0
Date: 04-21-05																																				0
1B-2 Beach Seine 1 of 3																			1																	1
1B-2 Beach Seine 2 of 3							8																													8
1B-2 Beach Seine 3 of 3			1				41												2																	44
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2																																				0
1B-1 Beach Seine 1 of 2																																				0
1B-1 Beach Seine 2 of 2																																				0
April 2005 subtotal	0	0	3	5	0	0	365	0	0	1	2	2	0	0	0	0	0	0	7	0	0	0	0	0	0	0	4	0	0	0	1	0	0	1	0	391

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	**Native**																		
Date: 05-05-05																																				
1A-6 Fyke net																													3						3
1A-7 Fyke net							6																							23						29
1A-10 Fyke net																																		1		1
1A-4 Beach Seine 1 of 4							1										1																			2
1A-4 Beach Seine 2 of 4							3																													3
1A-4 Beach Seine 3 of 4							5			12																				22				1		40
1A-4 Beach Seine 4 of 4				1																																1
1A-3 Beach Seine 1 of 3										1							2													1						4
1A-3 Beach Seine 2 of 3													1						3											3						7
1A-3 Beach Seine 3 of 3																	1										2			1						4
2-2 Beach Seine 1 of 2							25																				1								1	27
2-2 Beach Seine 2 of 2							15												2														1			18
1A-2 Otter Trawl 1 of 2				1								3																		1						5
1A-2 Otter Trawl 2 of 2				1							1	1																								3
1B-2 Beach Seine 1 of 2			1				29						15																						5	50
1B-2 Beach Seine 2 of 2							5																							6						11
3-1 Purse Seine 1 of 2																																				0
3-1 Purse Seine 2 of 2																																				0
Date: 05-06-05																																				
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2												1																				2				3
1B-1 Beach Seine 1 of 2																														1						1
1B-1 Beach Seine 2 of 2																																				0
2-1 Otter Trawl 1 of 2																																				0
2-1 Otter Trawl 2 of 2	1																1																		1	3
Date: 05-18-05																																				
1A-6 Fyke net										1									1											2						4
1A-7 Fyke net							4																							8						12
1A-10 Fyke net																														2				1		3
1A-4 Beach Seine 1 of 5							5																													5
1A-4 Beach Seine 2 of 5							5			1																										6
1A-4 Beach Seine 3 of 5							1			2			1						1																	5
1A-4 Beach Seine 4 of 5							1			2																				5				1		9
1A-4 Beach Seine 5 of 5							2																							4						6
1A-2 Otter Trawl 1 of 2										1															1					1						3
1A-2 Otter Trawl 2 of 2											1	1					1										3									6
1B-1 Beach Seine 1 of 2																																				0
1B-1 Beach Seine 2 of 2																																				0
3-1 Purse Seine 1 of 3																																	1			1
3-1 Purse Seine 2 of 3																																				0
3-1 Purse Seine 3 of 3																																				0
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2																																				0
Date: 05-19-05																																				
1B-2 Otter Trawl 1 of 3			1				3																												1	5
1B-2 Otter Trawl 2 of 3							7						1				1													9					2	20
1B-2 Otter Trawl 3 of 3							8										1													11			1		2	23
1A-3 Beach Seine 1 of 2							6						8						5											15			1			35
1A-3 Beach Seine 2 of 2							6			1	3		1				2		1								1			28	1				4	48
2-2 Beach Seine 1 of 2							25						1																						2	28
2-2 Beach Seine 2 of 2							22						1																	2					6	31
2-1 Otter Trawl 1 of 2																																				0
2-1 Otter Trawl 2 of 2												1																								1
May 2005 subtotal	1	0	2	3	0	0	184	0	0	21	5	7	29	0	0	0	10	0	13	0	0	0	0	0	1	0	7	0	0	148	1	2	4	4	24	466

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
									Introduced																	Native										
Date: 06-29-05																																				
1A-6 Fyke net							2					2																								4
1A-7 Fyke net							2					4																	1							7
1A-10 Fyke net																																		1		1
1A-4 Beach Seine 1 of 4							3				4	3					2													7						19
1A-4 Beach Seine 2 of 4							1																							3						4
1A-4 Beach Seine 3 of 4							7					1																		15						23
1A-4 Beach Seine 4 of 4							4			1																										5
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2																																				0
1A-2 Otter Trawl 1 of 2												2													2						1					5
1A-2 Otter Trawl 2 of 2				3								18																		1	1					23
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2																																				0
Date: 06-30-05																																				
1B-2 Beach Seine 1 of 2							18					24	1				1								1		1			26	1				1	74
1B-2 Beach Seine 2 of 2							27					58	7				6													18	1				10	127
3-1 Purse Seine 1 of 3	2						1																													3
3-1 Purse Seine 2 of 3													5																							5
3-1 Purse Seine 3 of 3							1						35																							36
1B-1 Beach Seine 1 of 2												4																		1	2					7
1B-1 Beach Seine 2 of 2												4																								4
1A-3 Beach Seine 1 of 2							4			1	6	6	4																	18	1					40
1A-3 Beach Seine 2 of 2							26				3	43					3													21					6	102
2-1 Otter Trawl 1 of 2																																				0
2-1 Otter Trawl 2 of 2												1															1					1			2	5
2-2 Beach Seine 1 of 2							25					12					4													19	8				7	75
2-2 Beach Seine 2 of 2							12					2	7				3														1					25
June 2005 subtotal	2	0	0	3	0	0	133	0	0	2	13	184	59	0	0	0	19	0	0	0	0	0	0	0	3	0	2	0	0	130	16	1	0	1	26	594

Table B-1. Juvenile and adult sampling results for the Napa River Fish Monitoring, July 2001–July 2002, January–July 2003, March–July 2004, and March–July 2005.

Location Code/ Gear Type/ Replicate Number	American shad	Black crappie	Bluegill	Carp	Channel catfish	Golden shiner	Inland silverside	Largemouth bass	Mosquitofish	Rainwater killifish	Shimofuri goby	Striped bass	Threadfin shad	Wakasagi	White catfish	White crappie	Yellowfin goby	Chinook salmon	Chum salmon	Delta smelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Speckled sanddab	Staghorn sculpin	Prickly/Staghorn sculpin	Sacramento pikeminnow	Sacramento splittail	Sacramento sucker	Starry flounder	Steelhead	Threespine stickleback	Tule perch	Total
	Introduced																	**Native**																		
Date: 07-28-05																																				
1A-6 Fyke net							2										12										1									15
1A-7 Fyke net							3						2																							5
1A-10 Fyke net																																				0
1A-4 Beach Seine 1 of 4							12				1		6																							19
1A-4 Beach Seine 2 of 4																																				0
1A-4 Beach Seine 3 of 4											1																									1
1A-4 Beach Seine 4 of 4										1							1																			2
1A-1 Otter Trawl 1 of 2																																				0
1A-1 Otter Trawl 2 of 2																																				0
1A-2 Otter Trawl 1 of 2																																				0
1A-2 Otter Trawl 2 of 2				1								10	13											4												28
1A-1 Otter Trawl 1 of 2																								1											1	2
1A-1 Otter Trawl 2 of 2																																				0
1A-3 Beach Seine 1 of 2							1						8				1										3			16						29
1A-3 Beach Seine 2 of 2							3				1																			1						5
1B-2 Beach Seine 1 of 2							1						9																							10
1B-2 Beach Seine 2 of 2							4						1																							5
2-2 Beach Seine 1 of 2													52				1																			53
2-2 Beach Seine 2 of 2							1				2		19																	7						29
Date: 07-29-05																																				
1B-2 Beach Seine 1 of 2																																				0
1B-2 Beach Seine 2 of 2																																				0
3-1 Purse Seine 1 of 2							2						4											3												9
3-1 Purse Seine 2 of 2							15						17											8												40
1B-1 Beach Seine 1 of 2				1								2																							1	4
1B-1 Beach Seine 2 of 2												6	3			1									1											11
2-1 Otter Trawl 1 of 2												56	32			4																			2	94
2-1 Otter Trawl 2 of 2												57	64			5	2								2		3								23	156
July 2005 subtotal	0	0	0	2	0	0	44	0	0	1	5	131	230	0	0	10	17	0	0	0	0	0	0	16	3	0	7	0	0	24	0	0	0	0	27	517
March-July 2005 subtotal of juvenile and adult fish	3	0	7	16	0	0	860	0	0	26	45	325	338	0	0	10	46	0	31	0	1	0	0	16	7	0	24	0	0	305	18	3	5	7	77	2,170
Total juvenile and adult fish, 2001, 2002, 2003, 2004, and 2005	49	107	8	55	1	3	5,549	4	9	40	619	1,063	1,332	1	1	10	284	4	39	1	11	1	3	4,032	16	8	418	98	3	762	44	88	8	83	207	14,961

Table B-2. Larval Fish Sampling Results for Napa River Fish Monitoring, March 2001–July 2002, January 2003–July 2003, March 2004–July 2004, and March 2005–July 2005.

Location Code/ Gear Type/ Replicate Number	Inland silverside	Shimofuri goby	Striped bass	Threadfin shad	Yellowfin goby	Arrow goby	Bay goby	Delta smelt	Jacksmelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Sacramento splittail	Sacramento sucker	Starry flounder	Threespine stickleback	Tule perch	Tridentiger spp. (Gobidae spp.)	Unidentified smelt	Unidentified centrarchid	Unidentified damaged	Total
	Introduced					Native																		
Date: 3-24-01																								
1A-1 CDFG 20-mm tow-net 1 of 3											2,917		15	12										2,944
1A-1 CDFG 20-mm tow-net 2 of 3		1			2			3			4,663		22	33										4,724
1A-1 CDFG 20-mm tow-net 3 of 3		9									3,974		7	8										3,998
1B-1 CDFG 20-mm tow-net 1 of 3								9			900		4	32										945
1B-1 CDFG 20-mm tow-net 2 of 3					3			19			955			89										1,066
1B-1 CDFG 20-mm tow-netl 3 of 3								12			494			31										537
2-1 CDFG 20-mm tow-net 1 of 3								4			98			35										137
2-1 CDFG 20-mm tow-net 2 of 3								8			78			67										153
2-1 CDFG 20-mm tow-net 3 of 3								4			74			67										145
March 2001Subtotal	0	10	0	0	5	0	0	59	0	0	14,153	0	48	374	0	0	0	0	0	0	0	0	0	14,649
Date: 4-7-01																								
1A-1 CDFG 20-mm tow-net 1 of 3					59			253			3,383		221	3										3,919
1A-1 CDFG 20-mm tow-net 2 of 3	1				23		3	259			3,453		432	12								1		4,183
1A-1 CDFG 20-mm tow-net 3 of 3		3			29		4	275			2,812		458	10										3,591
1B-1 CDFG 20-mm tow-net 1 of 3					14			439			673		92	39							1	1		1,258
1B-1 CDFG 20-mm tow-net 2 of 3					20			515			563		58	32										1,188
1B-1 CDFG 20-mm tow-netl 3 of 3					7			788			503		126	39										1,463
2-1 CDFG 20-mm tow-net 1 of 3					3			289			145		8	208										653
2-1 CDFG 20-mm tow-net 2 of 3					2			194			140		8	175								1		519
2-1 CDFG 20-mm tow-net 3 of 3					3			263			103		8	84										461
April 2001 Subtotal	1	3	0	0	160	0	7	3,275	0	0	11,775	0	1,411	602	0	0	0	0	0	0	1	3	0	17,235
Date: 5-5-01																								
1A-1 CDFG 20-mm tow-net 1 of 3		798		1	461		478	20		3	616	19	81											2,477
1A-1 CDFG 20-mm tow-net 2 of 3		822			646		1130	21	1	6	1,473	25	105		1									4,230
1A-1 CDFG 20-mm tow-net 3 of 3		457	676			9	104	17	1	2	652		79											1,997
1B-1 CDFG 20-mm tow-net 1 of 3		962			266		61	87		9	251	2	37	1								1		1,676
1B-1 CDFG 20-mm tow-net 2 of 3		1071			328		85	92		10	314		34											1,934
1B-1 CDFG 20-mm tow-netl 3 of 3		1004			491		102	75		6	331	3	39		1									2,052
2-1 CDFG 20-mm tow-net 1 of 3		573	1		276		2	50		10	134					1		1						1,048
2-1 CDFG 20-mm tow-net 2 of 3		537	1		587		13	68		16	171		2									1		1,395
2-1 CDFG 20-mm tow-net 3 of 3		1658			64		13	132		18	232		15											2,132
May 2001 Subtotal	0	7,882	678	1	3,119	9	1,988	562	2	80	4,174	49	392	1	2	1	0	1	0	0	0	2	0	18,941

Location Code/ Gear Type/ Replicate Number	Inland silverside	Shimofuri goby	Striped bass	Threadfin shad	Yellowfin goby	Arrow goby	Bay goby	Delta smelt	Jacksmelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Sacramento splittail	Sacramento sucker	Starry flounder	Threespine stickleback	Tule perch	Tridentiger spp. (Gobidae spp.)	Unidentified smelt	Unidentified centrarchid	Unidentified damaged	Total
	Introduced					Native																		
Date: 6-4-01																								
1A-1 CDFG 20-mm tow-net 1 of 3		399			1							7												407
1A-1 CDFG 20-mm tow-net 2 of 3		237										4												241
1A-1 CDFG 20-mm tow-net 3 of 3		432									1	2												435
1B-1 CDFG 20-mm tow-net 1 of 3		1										1												2
1B-1 CDFG 20-mm tow-net 2 of 3		739										1												740
1B-1 CDFG 20-mm tow-netl 3 of 3		806										1												807
2-1 CDFG 20-mm tow-net 1 of 3		493		1				1																495
2-1 CDFG 20-mm tow-net 2 of 3		426																						426
2-1 CDFG 20-mm tow-net 3 of 3	1	185											1											187
June 2001 Subtotal	1	3,718	0	1	1	0	0	1	0	0	1	16	1	0	0	0	0	0	0	0	0	0	0	3,740
2001 Subtotal of larval fish	2	11,613	678	2	3,285	9	1,995	3,897	2	80	30,103	65	1,852	977	2	1	0	1	0	0	1	5	0	54,565
Date: 3/25/02																								
1A-6 Fyke												2	2										6	10
1A-7 Fyke																								0
1A-4 Beach Seine (North End) 1 of 2													1											1
1A-4 Beach Seine (South End) 2 of 2													11											11
1A-2 Otter Trawl 1 of 2					1							3	2										34	40
1A-2 Otter Trawl 2 of 2																							1	1
Date: 3/26/02																								
1B-1 Otter Trawl 1 of 2																								0
1B-1 Otter Trawl 2 of 2																				1				1
1A-1 Otter Trawl 1 of 2																							2	2
1A-10 Fyke																								0
March 2002 Subtotal	0	0	0	0	1	0	0	0	0	0	0	5	16	0	0	0	0	0	0	1	0	0	43	66
Date: 4/8/02																								
1A-1 Otter Trawl 1 of 2					1								1											2
1A-1 Otter Trawl 2 of 2					1																			1
2-1 Otter Trawl 1 of 1					3								2											5
1A-4 (North End) Beach Seine 1 of 4													3											3
1A-4 (North End) Beach Seine 2 of 4	2												1									5		8
1A-10 Fyke											5		6											11
Date: 4/9/02																								
2-1 Otter Trawl 1 of 3					10																		2	12
2-1 Otter Trawl 2 of 3					2																			2
1B-1 Otter Trawl 1 of 2																								0
1B-1 Otter Trawl 2 of 2					2																			2

Location Code/ Gear Type/ Replicate Number	Inland silverside	Shimofuri goby	Striped bass	Threadfin shad	Yellowfin goby	Arrow goby	Bay goby	Delta smelt	Jacksmelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Sacramento splittail	Sacramento sucker	Starry flounder	Threespine stickleback	Tule perch	Tridentiger spp. (Gobidae spp.)	Unidentified smelt	Unidentified centrarchid	Unidentified damaged	Total
	Introduced					Native																		
Date: 4/22/02																								
1A-4 Beach Seine 1 of 2													1											1
Date: 4/23/02																								
1A-1 Otter Trawl 1 of 1																								0
1B-1 Otter Trawl 1 of 2					9																		2	11
1B-1 Otter Trawl 2 of 2					1																			1
April 2002 Subtotal	2	0	0	0	29	0	0	0	0	0	5	0	14	0	0	0	0	0	0	0	0	5	4	59
Date: 5/22/02																								
2-1 Otter Trawl 1 of 3		61																						61
2-1 Otter Trawl 3 of 3		73			1																			74
1B-1 Otter Trawl 1 of 2		13																						13
May 2002 Subtotal	0	147	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	148
Date: 6/21/02																								
1A-2 Otter Trawl 1 of 2		9																						9
1A-2 Otter Trawl 2 of 2		40																						40
2-1 Otter Trawl 2 of 2		63																						63
June 2002 Subtotal	0	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	112
2002 Subtotal of larval fish	2	259	0	0	31	0	0	0	0	0	5	5	30	0	0	0	0	0	0	1	0	5	47	385
Date: 2/26/03																								
1A-1 Otter Trawl 1 of 2											4												2	6
1A-1 Otter Trawl 2 of 2											12												3	15
1A-2 Otter Trawl 1 of 2											41													41
February 2003 Subtotal	0	0	0	0	0	0	0	0	0	0	57	0	0	0	0	0	0	0	0	0	0	0	5	62
Date: 3/13/03																								
1B-1 Otter Trawl 1 of 2											12												5	17
1B-1 Otter Trawl 2 of 2											74												9	83
2-1 Otter Trawl 1 of 2											152												38	190
2-1 Otter Trawl 2 of 2											1,262												47	1,309
1A-1 Otter Trawl 1 of 2											292												22	314
1A-1 Otter Trawl 2 of 2					2						586												45	633
1A-2 Otter Trawl 1 of 2					2						166												2	170
1A-2 Otter Trawl 2 of 2					1						155		1											157
Date: 3/27/03																								
1A-6 Fyke	1												2											3
1A-7 Fyke											3		1											4
Date:3/28/03																								
1A-1 Otter Trawl 1 of 2		1									147			1									6	155
1A-1 Otter Trawl 2 of 2											59			2									3	64
March 2003 Subtotal	1	1	0	0	5	0	0	0	0	0	2,908	0	4	3	0	0	0	0	0	0	0	0	177	3,099

Location Code/ Gear Type/ Replicate Number	Inland silverside	Shimofuri goby	Striped bass	Threadfin shad	Yellowfin goby	Arrow goby	Bay goby	Delta smelt	Jacksmelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Sacramento splittail	Sacramento sucker	Starry flounder	Threespine stickleback	Tule perch	Tridentiger spp. (Gobidae spp.)	Unidentified smelt	Unidentified centrarchid	Unidentified damaged	Total
	Introduced					Native																		
Date: 4/10/03																								
1A-1 Otter Trawl 1 of 2											2													2
1A-1 Otter Trawl 2 of 2											8													8
1B-1 Otter Trawl 1 of 2											53		1										1	55
1B-1 Otter Trawl 2 of 2											14												4	18
2-1 Otter Trawl 1 of 2											2													2
1A-2 Otter Trawl 1 of 2					5						246						1						3	255
1A-2 Otter Trawl 2 of 2											202			1			1							204
Date: 4/11/03																								
1A-6 Fyke											21													21
Date: 4/24/03																								
1A-1 Otter Trawl 1 of 2											2		1											3
1A-1 Otter Trawl 2 of 2											3													3
1A-2 Otter Trawl 1 of 2											11													11
1A-2 Otter Trawl 2 of 2		1									15													16
Date: 4/25/03																								
1A-6 Fyke											1													1
1A-7 Fyke		1									2		5											8
April 2003 Subtotal	0	2	0	0	5	0	0	0	0	0	582	0	7	1	0	0	2	0	0	0	0	0	8	607
Date: 6/7/03																								
1A-6 Fyke			4																					4
1A-7 Fyke			1																					1
2-1 Otter Trawl 1 of 2			73																					73
2-1 Otter Trawl 2 of 2			21																					21
1A-4 Beach Seine 1 of 4			11																					11
Date: 6/8/03																								
1A-1 Otter Trawl 1 of 2			3																					3
1A-1 Otter Trawl 2 of 2			9																					9
2-1 Otter Trawl 1 of 2			27																					27
1B-1 Otter Trawl 1 of 2			30																					30
1B-1 Otter Trawl 2 of 2			33																					33
1A-2 Otter Trawl 1 of 2			13																					13
1A-2 Otter Trawl 2 of 2			5																					5
1A-3 Beach Seine 1 of 2			2																					2
1A-3 Beach Seine 2 of 2			5																					5
June 2003 Subtotal	0	0	237	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	237
Date: 7/24/03																								
2-1 Otter Trawl 1 of 2			1																					1
1B-1 Otter Trawl 1 of 2			1																					1
July 2003 Subtotal	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
2003 Subtotal of larval fish	1	3	239	0	10	0	0	0	0	0	3,547	0	11	4	0	0	2	0	0	0	0	0	190	4,007

Location Code/ Gear Type/ Replicate Number	Inland silverside	Shimofuri goby	Striped bass	Threadfin shad	Yellowfin goby	Arrow goby	Bay goby	Delta smelt	Jacksmelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Sacramento splittail	Sacramento sucker	Starry flounder	Threespine stickleback	Tule perch	Tridentiger spp. (Gobidae spp.)	Unidentified smelt	Unidentified centrarchid	Unidentified damaged	Total
	Introduced					Native																		
Date: 4/15/04																								
2-1 Otter Trawl 1of 3																			10					10
1A-2 Otter Trawl 2 of 2													1										2	3
Date: 4/16/04																								
1A-6 Fyke											16		9											25
1A-10 Fyke													6											6
Date: 4/30/04																								
2-1 Otter Trawl 2 of 2					2								1										1	4
1A-2 Otter Trawl 1 of 2											1													1
1A-2 Otter Trawl 2 of 2											3												1	4
April 2004 Subtotal	0	0	0	0	2	0	0	0	0	0	20	0	17	0	0	0	0	0	10	0	0	0	4	53
Date: 05/14/04																								
2-1 Otter Trawl 1 of 2		1																						1
2-1 Otter Trawl 2 of 2		10																						10
Date: 05/13/04																								
1A-1 Otter Trawl 1 of 2																				12				12
May 2004 Subtotal	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	23
Date: 6/15/04																								
2-1 Otter Trawl 1 of 2		23																					2	25
June 2004 Subtotal	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	25
2004 Subtotal of larval fish	0	34	0	0	2	0	0	0	0	0	20	0	17	0	0	0	0	0	10	12	0	0	6	101
Date: 4/20/05																								
1A-2 Otter Trawl 2 of 2		2																						2
1A-6 Fyke Net		1									1													2
April 2005 Subtotal	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4

Location Code/ Gear Type/ Replicate Number	Inland silverside	Shimofuri goby	Striped bass	Threadfin shad	Yellowfin goby	Arrow goby	Bay goby	Delta smelt	Jacksmelt	Long-jawed mudsucker	Longfin smelt	Northern anchovy	Pacific herring	Prickly sculpin	Sacramento splittail	Sacramento sucker	Starry flounder	Threespine stickleback	Tule perch	Tridentiger spp. (Gobidae spp.)	Unidentified smelt	Unidentified centrarchid	Unidentified damaged	Total
	Introduced					**Native**																		
Date: 5/5/05																								
1A-6 Fyke													1											1
1A-2 Otter Trawl 1 of 2					2																			2
1B-1 Beach Seine 1 of 2		1																						1
Date: 5/18/05																								
1A-1 Otter Trawl 1 of 2											1													1
1A-2 Otter Trawl 1 of 2					1						1													2
1A-2 Otter Trawl 2 of 2		1			2						3													6
1B-1 Beach Seine 2 of 2		1																						1
1A-7 Fyke Net		1																						1
May 2005 Subtotal	0	4	0	0	5	0	0	0	0	0	5	0	1	0	0	0	0	0	0	0	0	0	0	15
Date: 6/29/05																								
1A-1 Otter Trawl 1 of 2		41	2																					43
2-1 Otter Trawl 2 of 2			4	1									5											10
Date: 6/30/05																								
1A-3 Beach Seine 1 of 3																							1	1
1A-3 Beach Seine 3 of 3		2											3											5
1B-2 Beach Seine 1 of 2				1									1											2
1B-1 Otter Trawl 1 of 2		89	1																				5	95
1B-1 Otter Trawl 2 of 2		275	9		1								1							40			7	333
2-1 Otter Trawl 1 of 2		82	3																				7	92
2-1 Otter Trawl 2 of 2		263	6	2	1								5							15				292
June 2005 Subtotal	0	752	25	4	2	0	0	0	0	0	0	0	15	0	0	0	0	0	0	55	0	0	20	873
Date: 7/29/05																								
2-1 Otter Trawl 1 of 2		8																					4	12
2-1 Otter Trawl 2 of 2		23																						23
1B-1 Otter Trawl 2 of 2		1																						1
July 2005 Subtotal	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	36
2005 Subtotal of larval fish	0	791	25	4	7	0	0	0	0	0	6	0	16	0	0	0	0	0	0	55	0	0	24	928
Total larval fish, 2001, 2002, 2003, 2004, and 2005	5	12,700	942	6	3,335	9	1,995	3,897	2	80	33,681	70	1,926	981	2	1	2	1	10	68	1	10	267	59,991

Appendix C

Table C-1. Napa River Fisheries Monitoring Program environmental conditions during juvenile and adult fish sampling, 2001–2005.

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^oC)	Water Temperature Bottom (^oC)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
7/16/2001	1A-9	21.7	21.7	17.4	15.6	0.6	5.8	-	2.5	Clear	1.6
7/16/2001	3-1	24	23.1	7.6	9.3	0.6	6.4	5.0	4.5	Clear	1.0
7/16/2001	1A-2	20.8	20.8	17.1	17.3	0.6	4.3	0.0	6.0	Clear	1.5
7/16/2001	3-1	24	23.1	7.6	9.3	0.6	6.4	5.0	4.5	Clear	1.0
7/17/2001	1A-8	25.6	25.6	13.9	14.3	0.9	9.9	10.8	0.6	Clear	1.2
7/17/2001	1A-5	23.8	23.8	10.1	12.9	0.6	5.9	5.7	0.6	Clear	1.5
7/17/2001	1A-6	26.9	26.9	17.2	18.1	0.9	8.9	9.9	1.5	Clear	1.2
7/17/2001	1A-3	23.5	23.6	10.0	9.8	0.6	5.5	5.6	0.3	Clear	1.7
7/17/2001	1A-7	26.8	26.7	10.4	11.7	0.9	8.7	8.6	0.6	Clear	1.5
7/17/2001	1A-10	26.9	26.5	18.2	18.2	0.8	6.0	6.0	1.0	Clear	1.5
8/14/2001	1A-4	19.2	19.2	20.7	20.7	0.3	2.7	2.7	0.3	Overcast	1.7
8/14/2001	1A-4	19.2	19.2	20.7	20.7	0.3	2.7	2.7	0.3	Clear	1.6
8/14/2001	1A-10	23.6	23.6	20.6	20.6	0.6	7.4	7.4	1.3	Overcast	1.1
8/14/2001	1A-8	24.8	24.9	20.5	20.6	0.6	9.6	9.9	0.4	Clear	1.1
8/14/2001	1A-7	26.9	26.9	20.6	26.9	-	10.7	10.7	0.3	Clear	1.2
8/14/2001	1A-6	25.8	25.7	20.9	20.9	0.6	9.1	9.5	1.2	Clear	1.3
8/14/2001	1A-3	25.2	25.4	19.6	19.5	1.8	5.3	5.4	0.6	Clear	1.3
8/14/2001	1A-5	23.9	23.6	20.1	20.1	0.3	5.1	4.8	0.6	Clear	0.4
8/15/2001	2-1	23.6	22.5	19.3	19.4	0.5	5.8	3.0	7.0	Clear	0.5
8/15/2001	1B-1	23.3	21.8	19.3	20.8	0.3	6.8	4.1	5.0	Clear	0.5
8/15/2001	1A-9	21	21.5	20.7	20.3	0.4	3.5	3.8	3.0	Overcast	0.7
8/15/2001	3-1	23.3	23.4	17.1	17.4	0.5	5.6	5.4	5.1	Clear	1.1
8/15/2001	1A-1	22.8	21.6	20.3	20.6	0.6	5.9	3.6	6.0	Clear	1.5
8/15/2001	1A-2	23.8	23.5	20.9	20.8	0.5	6.5	6.0	1.5	Overcast	1.4
9/11/2001	1A-4	20.1	20.1	21.6	21.9	0.5	3.1	0.1	1.0	Clear	1.3
9/11/2001	1A-4	20.1	20.1	21.6	21.9	0.5	3.1	0.1	1.0	Clear	1.3

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^oC)	Water Temperature Bottom (^oC)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
9/11/2001	1A-9	20.4	20.7	22.2	22.2	0.6	3.9	3.6	3.3	Clear	0.7
9/11/2001	1A-9	20.4	20.7	22.2	22.2	0.6	3.9	3.6	3.3	Clear	0.7
9/11/2001	3-1	22.6	21.9	18.0	19.4	0.5	5.7	4.1	3.3	Clear	1.1
9/11/2001	3-1	22.6	21.9	18.0	19.4	0.5	5.7	4.1	3.3	Clear	1.4
9/11/2001	2-1	22.6	21.6	20.3	21.3	0.4	7.0	3.4	3.4	Clear	1.2
9/11/2001	1B-1	22.6	21.2	21.3	21.8	0.5	7.8	4.0	5.1	Clear	1.0
9/11/2001	1A-1	22.7	20.6	22.2	22.0	0.5	6.2	3.5	5.5	Clear	1.0
9/11/2001	1A-2	24.6	24.3	22.7	22.7	0.6	7.8	8.1	1.4	Clear	1.2
10/11/2001	1A-3	21.4	21.4	19.9	19.9	0.5	9.8	9.8	0.3	Overcast	1.5
10/11/2001	1A-4	17.8	17.8	20.9	20.9	0.5	7.4	7.4	0.2	Overcast	1.8
11/8/2001	1A-10	16.2	16.2	18.4	18.4	-	9.4	10.1	0.8	Clear	1.3
11/8/2001	1A-9	15.1	15.1	18.5	18.5	0.7	5.2	1.2	2.3	Clear	1.9
11/8/2001	1A-6	15.4	15.2	18.5	18.5	0.8	5.6	4.7	1.5	Clear	0.9
11/8/2001	3-1	15.4	15.6	15.0	15.8	0.6	4.5	3.9	7.3	Clear	1.5
11/8/2001	2-1	16.1	15.8	16.9	17.5	0.8	4.9	4.0	5.0	Clear	1.5
11/8/2001	1B-1	16.1	15.7	17.6	17.7	0.8	4.9	4.5	5.2	Clear	1.5
11/8/2001	1A-3	16.1	15.7	17.6	17.7	0.8	4.9	4.5	5.2	Clear	1.0
11/8/2001	1A-1	16	15.7	17.9	17.9	0.7	5.5	5.9	5.4	Clear	0.9
11/8/2001	1A-3	16.1	15.7	17.6	17.7	0.8	4.9	4.5	5.2	Clear	1.0
11/9/2001	1A-6	17.7	17.7	18.3	18.3	0.6	14.6	14.7	1.8	Clear	1.9
11/9/2001	1A-3	14.7	14.4	17.9	17.8	0.6	4.6	4.5	0.6	Clear	1.8
11/9/2001	1A-5	15.1	15.1	18.4	18.3	0.6	5.7	5.3	0.6	Clear	1.8
11/9/2001	1A-7	15.2	15.2	18.6	18.6	0.6	5.2	5.6	0.7	Clear	1.9
11/9/2001	1A-8	15.2	15.2	18.6	18.6	0.0	5.1	4.4	0.9	Clear	1.9
11/9/2001	1A-4	15.4	15.3	18.6	18.6	0.0	5.4	5.4	0.6	Clear	2.1
11/9/2001	1A-3	14.7	14.4	14.9	17.8	0.6	4.6	4.5	0.6	Overcast	1.8
12/10/2001	1A-1	11.6	11.5	0.3	0.3	0.2	9.5	9.5	6.3	Clear	0.9
12/10/2001	1A-3	11.9	12.0	0.2	0.2	0.2	9.8	9.8	0.6	Clear	1.8
12/10/2001	1A-4	11.7	11.7	0.5	0.5	0.2	8.8	8.8	0.6	Clear	1.8

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^oC)	Water Temperature Bottom (^oC)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
12/10/2001	1A-4	11.6	11.6	0.4	0.4	0.3	9.5	9.5	0.6	Clear	2.4
2/25/2002	1A-1	14.9	14.4	3.3	3.6	0.3	11.2	10.4	8.0	Clear	2.1
2/25/2002	1A-3	14.2	13.9	0.9	0.9	0.2	10.7	11.0	0.5	Clear	2.4
2/25/2002	1A-3	14.2	13.9	0.9	0.9	0.2	10.7	11.0	0.5	Clear	2.4
2/25/2002	1A-4	14.4	14.4	2.2	2.1	0.2	10.7	10.3	0.5	Clear	2.1
2/25/2002	1A-4	14.4	14.4	2.2	2.1	0.2	10.7	10.3	0.5	Clear	2.1
2/25/2002	1A-4	14.8	14.8	2.4	2.5	0.1	10.8	9.9	0.5	Clear	2.1
2/25/2002	1A-4	14.7	14.7	3.2	2.9	0.2	10.8	10.4	0.5	Clear	2.2
2/25/2002	1B-1	14.3	13.6	0.3	0.7	0.4	11.3	11.1	7.0	Clear	2.1
3/25/2002	1A-2	15.4	14.5	2.9	3.2	0.3	9.4	8.7	2.0	Overcast	2.1
3/25/2002	1A-3	15.2	14.8	0.3	0.3	0.5	10.0	9.9	0.5	Clear	1.4
3/25/2002	1A-4	14.5	14.4	2.5	2.5	0.2	8.5	8.0	0.5	Overcast	2.1
3/25/2002	1A-4	15.3	15.2	2.6	2.6	0.2	9.6	9.6	0.6	Overcast	2.1
3/25/2002	1A-6	15.3	15.2	2.6	2.6	0.2	9.6	9.6	0.6	Overcast	2.2
3/25/2002	1A-7	17.0	16.9	2.3	2.3	0.2	11.4	11.2	0.6	Overcast	2.2
3/25/2002	1A-7	17.0	16.9	2.3	2.3	0.2	11.4	11.2	0.6	Overcast	2.2
3/25/2002	1A-8	16.8	16.9	1.6	1.6	0.2	15.1	15.1	0.6	Overcast	2.2
3/26/2002	1A-1	15.4	14.2	1.3	5.4	0.4	9.9	2.0	8.0	Clear	2.1
3/26/2002	1A-10	16.5	16.3	3.4	3.4	0.3	9.8	9.7	1.2	Clear	2.2
3/26/2002	1A-9	14.6	14.7	2.3	3.2	0.2	9.0	1.8	1.5	Clear	2.2
3/26/2002	1A-9	14.6	14.7	2.3	3.2	0.2	9.0	1.8	1.5	Clear	2.2
3/26/2002	1B-1	14.5	14.0	0.7	0.7	0.4	9.6	9.0	7.0	Clear	2.1
3/26/2002	2-1	13.9	13.4	0.2	0.2	0.5	9.4	9.4	4.5	Clear	1.8
4/8/2002	1A-1	17.5	17.2	2.3	3.7	0.2	8.7	6.9	6.6	Overcast	1.5
4/8/2002	1A-1	17.5	17.2	2.3	3.7	0.2	8.7	6.9	6.6	Overcast	1.5
4/8/2002	1A-10	19.1	19.2	3.3	3.3	0.2	13.2	13.9	0.9	Overcast	1.9
4/8/2002	1A-4	17.2	17.0	0.9	1.7	0.3	8.0	8.5	0.6	Overcast	1.8
4/8/2002	1A-4	17.2	17.2	3.5	3.4	0.2	7.2	8.0	0.5	Overcast	2.0
4/8/2002	1A-4	17.3	17.3	4.2	4.2	0.2	7.2	6.9	0.6	Overcast	1.9

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^oC)	Water Temperature Bottom (^oC)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
4/8/2002	1A-6	19.2	19.2	3.4	3.5	0.2	12.6	12.3	0.7	Overcast	1.9
4/8/2002	1A-7	19.2	19.2	3.4	3.5	0.2	12.6	12.3	0.7	Overcast	1.9
4/8/2002	2-1	17.3	17.3	4.3	4.3	0.2	7.6	7.2	20.0	Overcast	1.8
4/9/2002	1A-8	17.0	17.0	4.3	4.3	0.3	7.7	7.7	1.0	Overcast	1.9
4/9/2002	1A-9	17.0	17.1	4.2	4.1	0.2	8.2	8.2	1.5	Overcast	1.5
4/9/2002	1B-1	16.8	16.7	1.5	2.0	0.2	8.8	8.2	4.4	Overcast	1.8
4/9/2002	1B-1	16.8	16.7	1.5	2.0	0.2	8.8	8.2	4.4	Overcast	1.8
4/9/2002	2-1	16.4	16.3	0.5	0.6	0.5	9.5	8.7	5.3	Overcast	1.9
4/9/2002	2-1	16.4	16.3	0.5	0.6	0.5	9.5	8.7	5.3	Overcast	1.9
4/22/2002	1A-3	20.8	19.8	2.8	3.1	0.5	10.6	11.8	0.6	Clear	1.6
4/22/2002	1A-4	17.5	17.4	6.3	6.3	0.0	8.1	7.6	0.4	Clear	1.7
4/22/2002	1A-4	17.5	17.4	6.3	6.3	0.0	8.1	7.6	0.4	Clear	1.7
4/22/2002	1A-4	17.0	17.0	6.1	6.1	0.0	8.3	8.5	0.5	Clear	2.0
4/22/2002	1A-6	26.2	26.2	5.6	5.6	0.2	19.1	19.1	0.3	Clear	2.0
4/22/2002	1A-7	22.5	22.2	5.3	5.4	0.2	15.5	14.9	0.3	Clear	2.0
4/22/2002	1A-8	22.5	22.2	5.3	5.4	0.2	15.5	14.9	0.0	Clear	2.0
4/23/2002	1A-1	18.8	18.0	5.0	6.8	0.4	10.0	7.7	4.3	Clear	2.0
4/23/2002	1A-10	17.7	16.8	4.5	5.3	0.4	8.1	7.3	1.3	Clear	2.0
4/23/2002	1A-2	21.8	19.2	6.2	6.5	0.5	9.3	5.4	2.4	Clear	1.9
4/23/2002	1A-9	19.0	18.8	4.9	6.4	0.3	8.5	7.0	1.1	Clear	1.6
4/23/2002	1B-1	20.1	18.3	2.6	4.1	0.6	11.5	8.8	6.4	Clear	2.0
4/23/2002	1B-1	20.1	18.3	2.6	4.1	0.6	11.5	8.8	6.4	Clear	2.0
4/23/2002	1B-1	20.1	18.3	2.6	4.1	0.6	11.5	8.8	6.4	Clear	2.0
4/23/2002	1B-1	20.1	18.3	2.6	4.1	0.6	11.5	8.8	6.4	Clear	2.0
4/23/2002	2-1	19.1	18.3	1.8	2.4	0.5	11.0	8.3	5.3	Clear	2.0
4/23/2002	2-1	19.1	18.3	1.8	2.4	0.5	11.0	8.3	5.3	Clear	2.0
4/23/2002	3-1	17.2	17.3	0.2	0.3	0.8	10.7	9.6	8.0	Clear	1.9
5/22/2002	1A-1	19.7	18.5	6.7	6.8	0.3	7.9	6.7	5.7	Clear	4.5
5/22/2002	1A-10	20.2	20.1	8.0	8.0	0.3	6.7	6.9	0.8	Clear	1.8

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^{o}C)	Water Temperature Bottom (^{o}C)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
5/22/2002	1A-2	20.7	18.6	8.1	8.3	0.2	7.1	6.2	1.7	Clear	1.5
5/22/2002	1A-7	20.5	19.2	8.2	8.3	0.3	6.9	6.4	0.2	Clear	1.8
5/22/2002	1A-8	20.2	19.3	8.1	8.2	0.2	7.0	4.0	0.4	Clear	1.8
5/22/2002	1B-1	18.4	17.8	6.0	6.4	0.2	7.4	6.4	5.7	Clear	5.7
5/22/2002	2-1	18.8	18.7	3.4	4.2	0.3	8.4	6.1	5.6	Clear	1.7
5/22/2002	2-1	18.8	18.7	3.4	4.2	0.3	8.4	6.1	5.6	Clear	1.7
5/23/2002	1A-3	20.8	20.7	5.2	5.2	0.2	7.8	7.7	0.6	Clear	1.4
5/23/2002	1A-4	19.6	19.2	8.4	8.4	0.2	6.0	5.6	0.4	Clear	1.8
5/23/2002	1A-4	20.8	20.6	8.4	8.5	0.2	7.4	5.3	0.5	Clear	1.7
5/23/2002	1A-9	25.0	24.6	1.5	7.6	0.2	9.5	9.1	1.2	Clear	1.1
5/23/2002	3-1	18.4	18.2	1.2	1.5	0.3	6.6	6.1	6.9	Clear	1.5
5/23/2002	3-1	18.4	18.2	1.2	1.5	0.3	6.6	6.1	6.9	Clear	1.5
5/23/2002	3-1	18.4	18.2	1.2	1.5	0.3	6.6	6.1	6.9	Clear	1.5
6/20/2002	1A-10	23.2	22.8	11.6	11.8	0.4	6.9	6.1	0.9	Clear	1.6
6/20/2002	1A-3	21.9	22.0	9.8	9.9	0.5	5.5	5.4	0.8	Clear	1.6
6/20/2002	1A-4	23.9	24.1	11.6	11.6	0.3	7.7	7.7	0.5	Clear	1.6
6/20/2002	1A-4	26.2	26.2	11.3	11.3	0.2	9.5	9.5	0.2	Clear	1.6
6/20/2002	1A-4	25.7	25.0	11.3	11.4	0.3	10.1	9.0	0.5	Clear	1.5
6/20/2002	1A-6	23.9	24.1	11.6	11.6	0.3	7.7	7.7	0.2	Clear	1.6
6/20/2002	1A-7	22.8	22.9	11.8	11.8	0.3	5.7	5.8	0.4	Clear	1.6
6/20/2002	1A-8	22.7	22.7	11.8	11.8	0.4	5.5	5.4	0.5	Clear	1.6
6/21/2002	1A-1	22.7	21.9	10.3	10.4	0.3	7.0	6.0	5.7	Clear	1.4
6/21/2002	1A-2	22.6	22.6	12.0	12.0	0.4	6.2	6.4	1.7	Clear	1.7
6/21/2002	1A-9	22.3	22.5	12.0	11.9	0.3	8.1	5.8	0.9	Clear	1.8
6/21/2002	2-1	24.3	23.1	8.3	8.5	0.4	6.5	5.8	6.4	Clear	1.7
6/21/2002	3-1	22.2	23.4	5.5	5.5	0.5	6.7	4.9	5.6	Overcast	1.4
6/21/2002	3-1	22.2	23.4	5.5	5.5	0.5	6.7	4.9	5.6	Overcast	1.4
7/19/2002	1A-3	20.3	22.5	14.7	14.8	0.4	6.2	6.4	1.8	Clear	1.7
7/19/2002	1A-3	20.3	22.5	14.7	14.8	0.4	6.2	6.4	1.8	Clear	1.7

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^{o}C)	Water Temperature Bottom (^{o}C)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
7/19/2002	1A-3	20.3	22.5	14.7	14.8	0.4	6.2	6.4	1.8	Clear	1.7
7/19/2002	1A-4	21.5	21.5	15.9	15.9	0.3	4.9	4.9	0.5	Clear	1.5
7/19/2002	1A-4	21.5	21.5	15.9	15.9	0.3	4.9	4.9	0.5	Clear	1.5
1/29/2003	1A-4	13.0	13.2	0.3	0.3	0.4	10.7	10.1	0.4	Clear	2.4
1/29/2003	1A-2	14.5	14.4	0.7	0.7	0.3	9.1	8.7	1.2	Clear	2.1
1/29/2003	3-1	13.3	13.3	0.1	0.1	1.2	10.4	11.6	6.9	Clear	2.2
1/29/2003	2-1	13.6	13.3	0.1	0.2	1.0	9.5	9.6	4.9	Overcast	1.4
1/29/2003	1B-1	13.9	13.6	0.2	0.2	0.8	9.0	9.4	1.0	Overcast	1.2
1/29/2003	1A-1	14.7	14.7	0.3	0.3	0.4	10.3	9.7	5.7	Overcast	0.9
1/31/2003	1A-3	14.2	13.7	0.3	0.3	0.4	12.2	10.3	0.6	Overcast	2.4
1/31/2003	2-2	13.2	13.1	0.2	0.2	0.7	9.8	10.3	0.7	Overcast	2.4
2/26/2003	3-1	12.9	13.0	0.2	0.2	1.8	9.6	9.0	3.1	Overcast	2.3
2/26/2003	2-1	13.2	13.1	0.2	0.2	1.1	9.9	9.7	5.6	Overcast	2.2
2/26/2003	1B-1	13.2	13.3	0.2	0.2	0.7	10.3	10.8	4.4	Overcast	1.3
2/26/2003	1A-2	13.9	13.9	1.8	1.9	0.3	9.8	7.6	1.5	Overcast	1.9
2/26/2003	1A-1	13.9	13.9	1.5	1.5	0.5	9.1	9.1	6.7	Overcast	1.6
2/27/2003	1A-4	13.6	13.6	0.0	0.0	0.3	14.0	14.0	0.3	Clear	2.3
2/27/2003	1A-3	12.9	12.8	0.5	0.5	0.5	10.2	10.2	1.1	Clear	2.1
2/27/2003	2-2	11.3	12.2	0.2	0.2	0.6	10.5	9.5	0.6	Clear	1.7
3/13/2003	1A-3	16.1	16.0	0.9	0.9	0.7	11.2	11.0	1.2	Overcast	1.2
3/13/2003	1A-4	15.3	15.2	3.8	3.8	0.3	9.2	9.5	0.5	Overcast	2.0
3/13/2003	1A-10	16.8	16.8	4.0	4.0	0.4	10.1	10.2	0.8	Clear	1.4
3/13/2003	1A-6	15.4	15.3	4.9	4.8	0.4	8.6	8.4	1.3	Overcast	2.1
3/13/2003	1A-7	15.3	15.3	4.6	4.6	0.3	8.7	8.7	0.7	Overcast	2.1
3/13/2003	3-1	16.6	16.8	0.2	0.2	1.4	10.1	9.8	1.7	Overcast	0.9
3/13/2003	2-1	16.3	16.3	0.2	0.3	0.6	13.1	9.5	1.4	Overcast	0.7
3/13/2003	1B-1	16.2	16.1	0.4	0.4	0.9	12.2	11.6	3.5	Light rain	0.3
3/13/2003	1A-2	16.2	16.1	4.3	4.3	0.4	9.6	9.6	1.8	Overcast	1.8
3/13/2003	1A-1	15.8	15.8	1.2	1.2	0.6	10.4	10.5	4.5	Overcast	0.1

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^{o}C)	Water Temperature Bottom (^{o}C)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
3/27/2003	1A-3	17.2	17.2	0.2	0.2	0.4	9.3	8.4	0.6	Clear	1.8
3/27/2003	1A-4	16.4	16.6	0.7	0.7	0.3	10.0	8.2	0.3	Clear	2.1
3/27/2003	1A-10	16.3	16.5	0.6	0.7	0.3	8.7	6.1	1.0	Clear	2.1
3/27/2003	1A-6	16.4	16.5	0.7	0.7	0.3	8.5	8.2	0.6	Clear	2.1
3/27/2003	1A-7	16.4	16.6	0.7	0.7	0.3	8.3	8.0	0.9	Clear	2.1
3/27/2003	3-1	15.9	15.7	0.1	0.1	0.3	9.1	9.0	2.3	Clear	1.5
3/28/2003	2-1	16.0	15.9	0.2	0.2	0.7	9.8	1.8	6.4	Clear	1.7
3/28/2003	1B-1	16.4	16.3	0.3	0.3	0.5	10.3	8.9	8.2	Clear	1.9
3/28/2003	1A-2	17.1	17.0	0.9	1.0	0.2	9.4	9.1	1.6	Clear	1.8
3/28/2003	1A-1	16.7	16.6	0.5	0.5	0.4	10.2	3.8	6.5	Clear	1.8
4/10/2003	2-1	16.7	15.7	0.2	2.5	1.0	10.4	6.7	4.4	Overcast	1.7
4/10/2003	1B-1	16.6	15.7	0.6	3.2	0.9	11.1	7.8	4.5	Overcast	1.2
4/10/2003	1A-2	15.1	15.5	3.0	4.3	0.5	10.3	8.3	1.9	Overcast	1.7
4/10/2003	1A-1	16.5	15.6	1.7	3.7	0.4	10.2	7.6	6.4	Overcast	1.0
4/10/2003	3-1	16.1	16.1	0.2	0.2	2.2	14.2	14.2	6.0	Overcast	1.4
4/11/2003	1A-4	15.8	15.8	3.9	4.0	0.5	7.9	7.8	0.5	Clear	1.9
4/11/2003	1A-3	16.6	16.6	1.3	1.3	0.7	11.5	9.8	1.1	Clear	1.6
4/11/2003	1A-10	15.6	15.7	4.2	4.3	0.3	8.2	7.4	1.0	Clear	1.8
4/11/2003	1A-6	15.8	15.8	4.3	4.1	0.4	8.2	7.9	1.3	Clear	1.8
4/11/2003	1A-7	15.7	15.7	4.1	4.1	0.5	9.4	8.2	0.6	Clear	1.8
4/24/2003	2-1	14.8	14.9	0.2	0.2	0.7	10.1	9.4	7.1	Light rain	1.9
4/24/2003	1B-1	15.3	15.5	0.3	0.5	0.5	9.5	9.6	5.0	Light rain	1.7
4/24/2003	1A-2	15.6	15.7	2.6	2.6	0.4	8.4	8.5	2.7	Overcast	1.7
4/24/2003	1A-1	15.3	15.6	1.9	2.1	0.4	9.4	8.9	5.9	Overcast	1.2
4/24/2003	3-1	14.2	14.2	0.2	0.2	1.5	11.8	11.3	7.6	Light rain	1.6
4/25/2003	1A-3	14.3	14.3	0.5	0.5	0.3	9.9	9.7	0.8	rain	1.7
4/25/2003	1A-4	15.0	15.2	2.4	2.4	0.3	8.5	8.3	0.6	rain	1.9
4/25/2003	1A-10	13.5	14.1	1.5	1.6	0.3	9.6	9.5	0.6	Light rain	1.9
4/25/2003	1A-6	15.0	15.2	2.4	2.4	0.3	8.5	8.3	0.6	rain	1.9

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^oC)	Water Temperature Bottom (^oC)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
4/25/2003	1A-7	14.9	15.0	2.0	2.1	0.2	8.8	8.7	0.9	rain	1.8
5/13/2003	3-1	17.2	17.3	0.2	0.1	2.1	9.0	9.3	6.4	Clear	1.7
5/13/2003	1A-3	17.7	17.6	0.2	0.2	0.5	9.5	9.0	0.3	Clear	1.3
5/13/2003	1A-4	18.7	18.4	0.3	0.3	0.2	9.6	6.5	0.2	Clear	1.4
5/13/2003	1A-10	24.1	24.1	0.3	0.3	0.2	11.1	9.6	0.7	Clear	1.1
5/13/2003	1A-6	23.5	23.3	0.3	0.3	0.3	16.0	14.5	0.3	Clear	1.1
5/13/2003	1A-7	25.4	25.2	0.3	0.3	0.2	16.5	17.5	1.2	Clear	1.1
5/13/2003	2-1	17.4	17.4	0.2	0.2	0.8	9.7	10.0	6.8	Clear	1.5
5/14/2003	1B-1	17.5	17.6	0.2	0.2	0.4	9.4	9.2	4.1	Overcast	0.9
5/14/2003	1A-2	18.8	18.7	0.5	0.5	0.3	8.8	8.6	1.9	Overcast	1.3
5/14/2003	1A-1	18.4	18.4	0.5	0.5	0.3	8.2	8.2	5.9	Overcast	1.1
6/7/2003	1A-4	20.0	20.1	2.6	2.6	0.4	6.4	5.5	0.3	Overcast	1.7
6/7/2003	1A-6	20.3	20.4	2.9	2.9	0.4	5.0	5.8	0.8	Overcast	1.8
6/7/2003	1A-7	20.1	20.2	2.8	2.8	0.4	6.1	6.8	0.3	Overcast	1.7
6/7/2003	1A-10	20.2	20.3	2.7	0.9	0.4	6.0	5.1	1.4	Overcast	1.8
6/7/2003	2-1	21.7	21.8	0.2	0.2	0.4	5.6	5.2	3.9	Overcast	1.1
6/7/2003	3-1	20.9	20.9	0.2	0.2	0.8	7.4	6.0	2.3	Overcast	1.2
6/8/2003	1A-1	20.5	20.1	1.7	2.2	0.4	6.6	6.4	5.1	Overcast	1.2
6/8/2003	1A-2	19.9	19.8	2.6	2.6	0.4	7.8	7.5	1.7	Overcast	1.4
6/8/2003	1A-3	20.7	20.7	1.3	1.3	0.3	7.1	7.0	0.8	Overcast	1.7
6/8/2003	1B-1	22.0	21.9	0.7	0.7	0.3	6.9	6.9	4.4	Overcast	1.0
6/8/2003	2-1	22.0	21.6	0.2	0.2	0.4	6.4	5.1	4.0	Clear	0.7
7/23/2003	3-1	26.0	26.1	4.3	5.0	0.4	7.2	5.8	1.7	Overcast	1.4
7/23/2003	1A-3	26.1	26.0	9.1	9.0	0.4	7.6	7.6	2.8	Overcast	1.4
7/23/2003	1A-7	23.8	24.0	9.1	10.8	0.4	10.5	5.1	1.0	Clear	1.3
7/23/2003	1A-10	24.1	24.1	10.7	10.7	0.4	5.7	5.8	0.8	Clear	1.2
7/23/2003	1A-6	23.8	23.7	10.4	10.5	0.4	4.6	4.7	0.9	Clear	1.6
7/23/2003	2-1	26.0	25.3	7.1	8.7	0.4	9.0	3.6	5.6	Overcast	1.1
7/23/2003	1A-4	24.5	24.4	11.4	11.4	0.6	6.3	6.2	1.9	Clear	1.6

Sample Date	USACE / Stillwater Site	Water Temperature Surface (°C)	Water Temperature Bottom (°C)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
7/23/2003	1A-2	22.8	22.3	10.7	10.7	0.5	4.9	5.7	1.0	Clear	1.4
7/24/2003	2-1	26.9	24.9	7.9	8.6	0.6	7.5	4.3	4.3	Clear	1.4
7/24/2003	1B-1	-	-	-	-	0.3	-	-	6.1	Clear	1.6
7/24/2003	1A-1	-	-	-	-	0.4	-	-	5.9	Clear	1.2
3/3/2004	1A-6	12.6	12.6	0.2	0.2	0.3	11.0	11.5	1.0	Clear	2.1
3/3/2004	1A-7	12.6	12.6	0.2	0.2	0.3	10.0	11.1	0.7	Clear	2.1
3/3/2004	1A-10	12.5	12.3	0.2	0.2	0.3	11.5	11.0	2.3	Clear	1.9
3/3/2004	1A-3	12.2	12.3	0.1	0.1	0.5	11.5	11.7	0.8	Overcast	2.1
3/3/2004	2-2	12.2	12.2	0.1	0.1	0.6	11.0	10.7	0.7	Overcast	1.9
3/3/2004	3-1	12.1	12.0	0.1	0.1	0.6	12.7	11.8	2.5	Light rain	1.4
3/4/2004	1A-1	13.5	13.4	0.2	0.2	0.4	11.4	11.7	6.3	Clear	1.1
3/4/2004	1A-2	12.7	12.5	0.2	0.2	0.4	10.6	10.4	0.7	Clear	2.1
3/4/2004	1B-1	12.6	12.3	0.1	0.1	0.4	11.6	10.9	4.2	Clear	1.3
3/4/2004	2-1	13.2	12.0	0.1	0.1	0.8	10.6	10.9	5.3	Clear	1.7
3/4/2004	1A-4	11.9	12.0	0.2	0.2	0.4	10.4	9.5	0.5	Clear	1.8
3/4/2004	1B-2	13.4	13.0	0.1	0.1	0.4	11.6	10.3	0.6	Clear	2.0
3/17/2004	1A-6	18.8	18.8	0.4	0.4	0.3	9.4	9.3	0.4	Clear	1.7
3/17/2004	1A-7	18.9	18.9	0.4	0.4	0.3	8.7	9.0	0.4	Clear	1.8
3/17/2004	1A-10	18.8	18.7	0.4	0.4	0.4	9.2	9.0	0.6	Clear	1.7
3/17/2004	1A-4	19.0	18.9	0.4	0.4	0.3	9.4	9.0	0.5	Clear	1.9
3/17/2004	1B-2	18.3	18.2	0.2	0.2	1.0	10.7	9.4	1.2	Clear	1.5
3/17/2004	3-1	16.9	16.7	0.1	0.1	1.8	10.2	10.1	3.3	Clear	1.7
3/18/2004	1A-1	18.4	18.3	0.2	0.2	0.6	11.3	11.0	9.2	Clear	0.8
3/18/2004	1A-2	21.1	20.8	0.9	0.9	0.7	8.6	8.3	2.9	Clear	1.9
3/18/2004	1B-1	20.1	17.7	0.2	0.2	0.7	12.3	10.4	4.6	Clear	1.5
3/18/2004	2-1	19.3	18.1	0.2	0.2	0.8	12.0	10.9	5.7	Clear	2.2
3/18/2004	1A-3	18.6	18.6	0.3	0.3	0.4	10.1	9.6	0.7	Clear	1.6
3/18/2004	2-2	17.7	17.7	0.2	0.2	1.2	12.0	11.4	0.6	Clear	1.9
4/15/2004	1A-2	19.6	19.5	4.0	4.0	0.3	18.8	18.2	0.4	Overcast	1.2

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^oC)	Water Temperature Bottom (^oC)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
4/15/2004	2-1	17.3	17.4	0.8	1.1	0.6	11.7	10.8	5.4	Clear	1.3
4/15/2004	1B-1	17.3	17.0	2.5	2.7	0.4	10.9	8.7	6.5	Overcast	1.7
4/15/2004	3-1	16.4	16.0	0.2	0.2	1.0	12.5	11.0	4.2	Overcast	1.8
4/15/2004	2-2	18.1	18.0	0.5	0.5	0.4	13.6	10.8	0.6	Overcast	1.8
4/15/2004	1A-1	18.0	17.6	2.2	2.4	0.4	12.3	7.9	4.9	Overcast	1.3
4/16/2004	1A-7	15.0	15.0	3.0	3.0	0.4	9.2	9.3	1.3	Clear	0.5
4/16/2004	1A-10	16.5	16.4	2.9	3.0	0.4	10.8	8.4	0.7	Clear	1.2
4/16/2004	1A-6	14.2	14.0	3.2	3.3	0.5	9.8	6.3	0.6	Clear	0.9
4/16/2004	1A-3	17.6	17.4	2.6	2.6	0.4	12.5	11.2	0.7	Light rain	1.9
4/16/2004	1A-4	15.0	15.0	3.0	3.0	0.4	9.2	9.3	1.3	Clear	1.5
4/16/2004	1B-2	18.5	18.5	1.8	1.8	0.1	12.3	11.5	0.5	Overcast	1.9
4/29/2004	1A-6	18.9	18.8	3.2	3.2	0.3	6.7	6.1	1.3	Clear	1.5
4/29/2004	1A-7	19.1	19.0	3.2	3.2	0.5	9.0	7.0	0.6	Clear	1.5
4/29/2004	1A-10	20.1	20.1	3.5	3.5	0.5	7.8	7.8	1.2	Clear	1.4
4/29/2004	2-2	21.5	21.5	0.8	0.8	0.5	11.5	9.4	0.4	Clear	1.6
4/29/2004	1B-2	21.6	21.5	1.5	1.5	0.5	13.5	12.5	1.1	Clear	1.2
4/29/2004	1A-3	20.7	20.8	2.2	2.2	0.3	10.6	10.8	0.3	Clear	1.7
4/29/2004	1A-4	18.6	18.5	3.2	3.2	0.4	7.1	6.6	1.0	Clear	1.5
4/30/2004	1A-1	20.3	20.2	4.0	4.3	0.5	8.1	8.2	5.8	Clear	1.4
4/30/2004	1A-2	20.3	20.3	4.2	4.2	0.4	7.8	8.2	2.0	Clear	1.7
4/30/2004	2-1	21.8	21.0	1.7	1.8	0.4	11.9	10.4	5.8	Clear	1.7
4/30/2004	1B-1	21.6	21.4	2.2	2.3	0.4	10.4	10.1	4.7	Clear	1.3
4/30/2004	3-1	21.0	20.7	0.3	0.3	0.8	10.2	9.5	2.8	Clear	1.8
5/13/2004	1A-6	19.3	19.3	6.4	6.4	0.3	7.1	7.4	0.7	Clear	1.5
5/13/2004	1A-7	19.5	19.5	6.5	6.5	0.4	7.5	6.6	0.4	Clear	1.5
5/13/2004	1A-10	19.6	19.6	6.8	6.9	0.4	7.4	7.8	0.6	Clear	1.4
5/13/2004	1A-3	21.6	22.0	4.9	5.0	0.4	11.7	11.0	0.9	Clear	1.6
5/13/2004	1A-4	19.0	18.6	6.4	6.4	0.4	7.0	6.5	0.6	Clear	0.6
5/13/2004	1A-3	21.6	20.2	5.4	6.4	0.4	10.4	8.6	5.7	Clear	0.8

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^{o}C)	Water Temperature Bottom (^{o}C)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
5/13/2004	1A-2	20.5	20.3	7.4	7.5	0.5	8.7	8.2	1.3	Clear	1.7
5/13/2004	1A-1	21.6	20.2	5.4	6.4	0.4	10.4	8.6	5.7	Clear	0.8
5/14/2004	1B-2	22.6	22.4	4.3	4.4	0.5	12.1	12.3	0.6	Overcast	1.3
5/14/2004	1B-1	21.1	20.8	5.3	5.4	0.4	8.6	8.2	4.3	Clear	1.2
5/14/2004	2-1	21.9	21.1	4.4	4.8	0.5	10.9	8.7	5.2	Clear	1.5
5/14/2004	2-2	22.5	21.2	2.4	4.1	0.5	12.1	8.7	2.1	Clear	1.7
5/14/2004	3-1	21.1	21.3	0.9	1.4	0.4	9.8	10.2	4.1	Overcast	1.1
6/15/2004	1A-6	23.6	23.5	11.3	11.3	0.7	6.4	5.9	1.2	Clear	1.1
6/15/2004	1A-7	23.7	23.3	11.1	11.2	0.6	7.0	6.7	1.2	Clear	1.1
6/15/2004	1A-10	29.4	29.3	10.5	10.6	0.3	10.3	9.7	0.6	Clear	1.1
6/15/2004	1A-4	22.7	22.6	10.3	10.3	0.4	5.6	5.5	0.5	Clear	1.3
6/15/2004	1B-1	23.7	23.2	8.2	8.3	0.4	6.5	6.5	6.5	Clear	1.1
6/15/2004	2-1	24.8	23.5	7.2	8.0	0.3	7.5	6.3	5.0	Clear	1.3
6/15/2004	1A-2	23.6	23.3	11.3	11.3	0.5	6.8	6.5	1.7	Clear	1.0
6/15/2004	1A-1	23.9	22.8	10.8	11.5	0.6	7.5	6.0	6.2	Clear	0.9
6/16/2004	1A-3	23.6	23.5	9.9	9.9	0.4	5.5	4.2	0.4	Clear	1.3
6/16/2004	1B-2	24.3	24.2	8.9	8.5	0.4	7.8	7.7	0.7	Clear	1.3
6/16/2004	2-2	24.4	24.4	8.4	8.4	0.5	7.5	7.2	1.6	Clear	1.1
6/16/2004	3-1	25.2	24.4	6.1	6.4	0.4	8.7	6.4	2.9	Clear	1.1
7/12/2004	1A-3	21.7	21.6	13.6	13.7	0.6	5.7	5.6	0.6	Clear	1.2
7/12/2004	1A-6	22.7	22.1	14.8	14.8	0.4	7.0	7.9	0.5	Clear	1.0
7/12/2004	1A-7	21.6	21.6	14.8	14.8	0.9	5.6	5.9	0.6	Clear	1.0
7/12/2004	1A-10	23.3	23.1	14.9	14.8	0.9	8.8	8.0	0.7	Clear	1.1
7/12/2004	1A-4	21.6	21.6	14.8	14.8	0.9	5.6	5.9	0.6	Clear	1.1
7/12/2004	1B-1	23.6	21.6	12.8	13.7	0.5	8.3	6.0	4.8	Clear	0.9
7/12/2004	2-1	23.9	22.1	12.1	13.1	0.1	7.8	6.0	5.3	Clear	0.9
7/12/2004	1A-2	21.7	21.5	14.8	14.8	0.9	6.3	5.8	1.9	Clear	1.2
7/12/2004	1A-4	21.4	21.2	13.5	13.3	0.9	6.1	5.6	6.0	Overcast	1.2
7/13/2004	1B-2	22.4	22.4	13.0	13.0	0.3	6.1	6.1	0.3	Clear	1.3

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^{o}C)	Water Temperature Bottom (^{o}C)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
7/13/2004	2-2	23.2	23.1	11.5	11.7	0.9	7.5	6.5	1.0	Clear	1.3
7/13/2004	3-1	23.0	23.1	8.6	8.9	0.5	7.2	6.2	6.4	Overcast	1.2
3/9/2005	1A-3	15.6	15.4	0.2	0.2	0.5	9.0	9.8	0.9	Clear	2.1
3/9/2005	1A-4	15.7	15.7	0.3	0.3	0.4	9.2	6.6	0.4	Clear	2.0
3/9/2005	1A-6	14.8	14.8	0.4	0.4	0.3	6.8	6.3	0.6	Overcast	1.5
3/9/2005	1A-7	14.9	14.9	0.4	0.4	0.3	7.2	6.9	0.5	Overcast	1.6
3/9/2005	1B-2	17.8	16.9	0.2	0.2	0.6	10.0	9.9	0.9	Clear	2.0
3/9/2005	2-2	16.6	15.8	0.1	0.1	1.0	9.2	10.0	0.5	Clear	1.5
3/9/2005	1A-1	17.1	16.9	0.3	0.3	0.4	9.9	9.7	6.2	Clear	1.0
3/9/2005	1A-2	15.4	15.3	0.2	0.2	0.5	8.8	9.3	1.4	Overcast	1.2
3/9/2005	2-1	15.7	15.2	0.1	0.1	1.0	9.1	9.3	5.9	Clear	1.5
3/10/2005	1B-1	15.7	15.6	0.2	0.2	0.7	9.6	9.3	6.1	Clear	1.4
3/10/2005	3-1	16.6	15.8	0.1	0.1	1.4	9.1	8.9	3.0	Clear	1.9
3/23/2005	1A-6	12.0	12.0	0.3	0.3	0.2	7.8	6.7	0.7	Light rain	1.1
3/23/2005	1A-7	12.0	12.0	0.3	0.3	0.2	7.7	7.1	0.4	Light rain	1.1
3/23/2005	1A-10	12.4	12.5	0.2	0.2	0.2	8.0	8.2	0.8	Light rain	1.0
3/23/2005	1A-2	12.0	12.0	0.3	0.3	0.2	7.7	7.1	0.4	Light rain	1.2
3/23/2005	1A-1	13.4	13.3	0.1	0.1	0.2	9.5	9.4	6.5	Overcast	1.8
3/23/2005	1B-1	13.5	13.5	0.1	0.1	0.2	9.9	9.6	2.6	Overcast	1.3
3/23/2005	1A-3	13.4	13.3	0.1	0.1	0.2	9.2	8.5	0.5	Overcast	1.8
3/23/2005	1A-4	13.9	13.9	0.1	0.1	0.2	12.3	9.7	2.7	Overcast	2.0
3/23/2005	1B-2	12.9	12.9	0.1	0.1	0.1	9.7	9.7	0.5	Overcast	1.6
3/24/2005	2-1	13.6	12.7	0.1	0.1	0.4	10.0	10.0	5.5	Clear	1.9
3/24/2005	2-2	12.7	12.7	0.1	0.1	0.3	9.8	9.6	0.5	Clear	1.5
3/24/2005	3-1	12.5	12.4	0.1	0.1	0.5	9.8	9.8	1.7	Clear	1.7
4/20/2005	1A-6	17.2	17.2	1.7	1.7	0.4	8.3	7.5	1.0	Clear	1.7
4/20/2005	1A-7	17.5	17.5	1.5	1.5	0.5	8.1	8.2	0.7	Clear	1.7
4/20/2005	1A-10	17.4	17.2	1.4	1.7	0.5	8.7	7.3	1.4	Clear	1.7
4/20/2005	1A-2	18.1	17.8	1.5	1.6	0.4	8.7	8.4	2.2	Clear	1.6

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^oC)	Water Temperature Bottom (^oC)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
4/20/2005	2-1	15.8	15.8	0.2	0.2	1.1	9.9	9.6	4.8	Overcast	0.9
4/20/2005	3-1	15.6	15.7	0.2	0.2	1.9	9.6	11.3	2.7	Overcast	1.2
4/20/2005	1A-4	17.6	17.5	1.3	1.3	0.4	8.2	7.5	0.4	Clear	1.7
4/20/2005	1A-3	18.9	18.5	0.3	0.3	0.5	10.5	9.0	0.5	Clear	1.3
4/20/2005	2-2	16.2	16.2	0.2	0.2	1.1	10.6	10.6	0.4	Overcast	1.4
4/21/2005	1A-1	18.6	17.8	1.3	1.7	0.3	8.5	8.1	6.7	Clear	1.6
4/21/2005	1B-1	18.0	17.5	0.4	0.4	0.6	9.6	9.7	5.1	Clear	1.5
4/21/2005	1B-2	19.6	18.9	0.2	0.2	0.5	10.2	12.7	0.5	Clear	1.7
5/5/2005	1A-6	17.1	17.1	2.8	2.8	0.3	3.9	4.0	1.2	Overcast	0.9
5/5/2005	1A-7	17.1	17.1	2.8	2.8	0.4	4.8	5.2	1.4	Overcast	0.9
5/5/2005	1A-10	18.0	17.8	2.2	2.3	0.5	6.1	5.3	0.3	Overcast	0.8
5/5/2005	1A-4	18.5	18.5	2.1	2.1	0.4	6.5	6.5	0.2	Overcast	1.2
5/5/2005	1A-3	19.6	19.5	2.0	2.0	0.4	7.6	6.9	0.6	Overcast	1.8
5/5/2005	2-2	21.1	21.1	0.2	0.2	0.4	10.4	11.0	0.5	Overcast	1.5
5/5/2005	1A-2	17.1	17.1	2.8	2.8	0.4	4.8	5.2	1.4	Overcast	0.9
5/5/2005	1B-2	20.1	20.0	0.7	0.7	0.5	10.2	10.2	0.4	Overcast	1.6
5/5/2005	3-1	17.8	17.8	0.2	0.2	1.4	8.6	5.8	1.9	Clear	1.0
5/6/2005	2-1	18.8	18.7	0.8	0.8	0.4	8.5	8.3	6.5	Overcast	1.2
5/6/2005	1A-1	18.9	19.0	4.0	4.1	0.5	7.2	6.6	3.2	Overcast	1.7
5/6/2005	1B-1	18.9	18.8	1.9	1.9	0.5	7.8	7.5	1.5	Overcast	1.5
5/18/2005	3-1	16.4	16.0	0.1	0.1	0.2	8.4	8.3	3.3	Overcast	0.9
5/18/2005	1B-1	18.5	18.6	0.2	0.2	0.3	7.8	7.9	4.8	Heavy rain	1.2
5/18/2005	1A-1	18.3	18.4	0.7	0.6	0.4	7.0	6.9	4.6	Heavy rain	1.1
5/18/2005	1A-2	18.4	18.5	1.4	1.4	0.3	6.6	6.2	5.5	rain	1.4
5/18/2005	1A-4	18.3	18.3	0.9	0.9	0.3	6.0	6.0	0.3	rain	1.5
5/18/2005	1A-10	18.5	18.5	1.2	1.2	0.3	2.4	6.0	2.1	Light rain	1.4
5/18/2005	1A-7	18.4	18.4	1.1	1.1	0.2	6.1	6.1	0.3	rain	1.5
5/18/2005	1A-6	18.4	18.5	1.1	1.1	0.3	5.9	6.0	1.7	rain	1.4
5/19/2005	1A-3	17.5	17.2	0.1	0.1	0.1	7.8	7.5	0.4	Overcast	1.6

Sample Date	USACE / Stillwater Site	Water Temperature Surface (^{o}C)	Water Temperature Bottom (^{o}C)	Water Salinity Surface (ppt)	Water Salinity Bottom (ppt)	Water Turbidity (m)	Dissolved Oxygen Surface (mg/l)	Dissolved Oxygen Bottom (mg/l)	Water Depth (m)	Weather Condition	Tide Elevation (m)
5/19/2005	2-2	17.4	17.0	0.1	0.1	0.1	7.9	7.7	0.4	Overcast	1.5
5/19/2005	1B-2	15.9	15.8	0.1	0.1	0.1	7.2	7.3	0.4	Overcast	1.3
5/19/2005	2-1	16.8	16.2	0.1	0.1	0.2	8.2	7.9	4.5	Overcast	1.0
6/29/2005	1A-10	20.1	20.1	4.0	4.0	0.4	5.2	4.8	1.2	Overcast	1.5
6/29/2005	1A-6	20.0	20.1	3.9	3.9	0.4	5.2	5.2	1.4	Overcast	1.5
6/29/2005	1A-7	20.1	20.1	3.9	3.9	0.4	5.0	5.2	0.4	Overcast	1.5
6/29/2005	1A-1	22.2	21.4	2.1	2.2	0.3	6.2	6.6	4.0	Clear	0.7
6/29/2005	1A-4	20.0	20.0	3.7	3.7	0.2	5.2	5.2	0.6	Overcast	1.6
6/29/2005	1A-2	23.1	23.6	3.5	3.6	0.2	6.7	6.2	1.4	Clear	1.0
6/30/2005	1A-3	21.7	21.7	2.6	2.6	0.2	5.2	5.2	0.3	Clear	1.6
6/30/2005	1B-1	21.7	21.8	1.9	2.0	0.3	5.8	6.4	5.3	Clear	1.0
6/30/2005	1B-2	23.0	22.8	1.7	1.8	0.4	6.5	7.0	0.5	Clear	1.5
6/30/2005	2-1	24.7	22.9	0.5	1.0	0.3	8.3	7.7	4.7	Clear	1.0
6/30/2005	2-2	23.8	23.6	0.7	0.7	0.2	7.8	8.4	0.5	Clear	1.5
6/30/2005	3-1	23.1	22.7	0.2	0.2	0.4	6.3	7.3	3.9	Clear	1.2
7/28/2005	1A-10	22.7	22.8	9.6	9.7	0.8	4.8	3.7	1.0	Overcast	1.5
7/28/2005	1A-6	22.6	22.7	9.5	9.6	0.2	5.7	4.3	1.0	Clear	1.5
7/28/2005	1A-7	22.5	22.6	9.4	9.4	0.5	6.0	5.1	0.6	Clear	1.5
7/28/2005	1A-4	22.3	22.5	9.3	9.3	0.5	6.0	5.2	0.5	Clear	1.5
7/28/2005	1A-2	25.5	25.2	9.5	9.5	0.4	6.9	7.0	1.0	Clear	0.8
7/28/2005	1A-1	24.7	23.4	7.2	8.3	0.6	6.2	5.8	4.9	Clear	0.7
7/28/2005	1A-3	23.3	23.3	8.0	8.0	0.4	5.8	5.3	0.4	Clear	1.5
7/28/2005	2-2	24.7	24.6	4.8	6.3	0.5	6.2	6.3	0.6	Clear	1.1
7/28/2005	1B-2	24.1	23.9	6.7	7.0	0.5	6.5	6.0	0.7	Clear	1.3
7/29/2005	2-1	23.6	23.9	6.0	7.0	0.6	6.3	5.8	4.6	Clear	1.3
7/29/2005	3-1	24.6	24.2	3.9	4.8	0.5	5.6	4.5	2.2	Clear	1.5
7/29/2005	1B-1	23.9	22.9	8.2	8.5	0.6	6.7	5.6	4.8	Clear	2.4

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Spatial and temporal patterns of vertical distribution for three planktivorous fishes in Lake Washington

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Spatial and temporal patterns of vertical distribution for three planktivorous fishes in Lake Washington

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Abstract – We sampled three limnetic fish species: juvenile sockeye salmon (*Oncorhynchus nerka*), three-spine stickleback (*Gasterosteus aculeatus*) and longfin smelt (*Spirinchus thaleichthys*) in Lake Washington to quantify species-specific patterns of diel vertical migration (DVM). Catch-per-unit-effort data analysed from 15 years of midwater trawling documented seasonal and diel differences in vertical distributions for each species. These results were consistent with the hypothesis that the patterns of DVM in Lake Washington were affected by life history, size and morphology. Sockeye salmon showed clear DVM in spring but essentially no DVM in fall, remaining in deep water, whereas three-spine sticklebacks were prevalent at the surface at night in both seasons. In fall, distribution patterns may be explained by differences in thermal performance (e.g., sticklebacks favouring warm water), but the patterns were also consistent with inter-specific differences in predation risk. Younger sockeye salmon and longfin smelt were present in greater proportions higher in the water column during dusk and night periods than older conspecifics. Compared with sockeye salmon, the greater use by three-spine sticklebacks of surface waters throughout the diel cycle during weak thermal stratification in spring was consistent with the hypothesis that sticklebacks' armour reduces predation risk, but use of this warmer, metabolically beneficial stratum may also have promoted growth. This study illustrates variation in the vertical distribution of three sympatric planktivores and offers broader implications for the DVM phenomenon and applied lake ecology.

Key words: diel vertical migration; temperature; predator avoidance; planktivores

Introduction

Fish need to feed, but foraging is seldom the only factor, and often not the primary factor, affecting their movements and distribution. Conflicts with reproduction, predator avoidance and optimisation of physiological conditions often limit foraging in time and space (Eggers 1978; Coutant 1985, 1987; Clark & Levy 1988; Appenzeller & Leggett 1995; Beauchamp et al. 1997). The costs and benefits of foraging in a given area vary among species as a function of life history and among individuals as a function of size or other attributes that make them vulnerable to predation (Levy 1990). The vertical distribution of pelagic fishes can serve as a model for the study of such trade-offs (Clark & Levy 1988; Scheuerell & Schindler 2003; Hardiman et al. 2004; Jensen et al. 2006; Gjelland et al. 2009). Zooplankton densities are often higher in the epilimnion, but planktivorous fishes are more vulnerable to visual predators there than in deeper,

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darker waters where zooplankton are less abundant and detectable. In addition to vertical gradients in food availability and predation risk, vertical temperature gradients differentially affect the metabolic rates of predators and prey, further complicating the trade-offs associated with depth (Magnuson et al. 1979; Brandt et al. 1980; Wurtsbaugh & Neverman 1988). As foraging opportunities and predation risk vary with light levels over the 24-h period, planktivores often show diel vertical migrations (DVM).

Although temperature influences should be secondary to feeding and predation risk during daylight and crepuscular periods, thermal constraints could still be expressed as avoidance of temperatures that were stressful or detrimental to growth when the thermal experience of an individual is averaged over an entire diel cycle. At night, low light levels should inhibit feeding by both planktivorous and piscivorous fishes, so planktivores should occupy depths most beneficial for growth, unencumbered by the need to feed or avoid predators, although clear lakes under either high moon light (Luecke & Wurtsbaugh 1993) or excessive urban light pollution (Mazur & Beauchamp 2006; Kitano et al. 2008) may be exceptions to this pattern. Thermal optima vary among species (Coutant 1977; Magnuson et al. 1979), and the different DVM patterns of sympatric coregonids were best explained by differences in thermal ecology (Mehner et al. 2010). Temperatures above and below the optimum limit growth, but the limitation is generally more severe at incrementally warmer than cooler temperatures (Magnuson et al. 1979). The optimal temperature for growth also shifts to cooler temperatures for larger fish and at lower daily energy intake rates (Beauchamp 2009). These features of physiology suggest that DVM patterns should vary seasonally as a lake stratifies and mixes and as prey availability changes, but this seasonal shift was not observed in two coregonid species (Mehner et al. 2007).

Many fishes show DVM, but the patterns may differ among or within species in a given lake (e.g., Piet & Guruge 1997; Stockwell et al. 2010). Species less vulnerable to predation might be expected to spend more time feeding in profitable epilimnetic waters. The DVM patterns of two coregonids in Lake Superior revealed this pattern, as larger-bodied cisco had a shallower DVM than smaller kiyi (Stockwell et al. 2010). Moreover, fish of the same species may differ in the extent or timing of movement as a function of body size (Levy 1991). For example, a model indicated that older kokanee (nonanadromous sockeye salmon, *Oncorhynchus nerka*) tend to feed at and migrate to deeper depths than younger smaller fish in reservoirs where abundant large piscivorous lake trout *Salvelinus namaycush* imposed significant predation risk to all sizes of kokanee (Stockwell & Johnson 1999; Johnson & Martinez 2000). The opposite pattern was observed in lakes containing less abundant and smaller piscivores, presenting less predation risk for larger kokanee (Levy 1991).

Diel vertical migration of juvenile sockeye salmon has been closely studied in lakes around the Pacific Rim. These fish enter lakes in spring at a size of *ca.* 28 mm after emerging from gravel nests in streams or lake beaches (Quinn 2005), and they feed chiefly on zooplankton in the limnetic zone. They prey on large zooplankton if available (Eggers 1982) and display DVM to balance their foraging needs with predator avoidance (Eggers 1978; Clark & Levy 1988; Scheuerell & Schindler 2003). Predator avoidance, prey distribution and temperature all affect the timing of movement and depth distribution (Brett 1971; Clark & Levy 1988; Levy 1990, 1991; Beauchamp et al. 1997). Because salmonids and their predators are primarily visual foragers, feeding should be confined to daylight and crepuscular periods, and their vertical distribution should be influenced by trade-offs between predation risk and the profitability of feeding at any given depth.

Lake Washington, in Washington State, USA, serves as a model body of water for comparative work on DVM. The lake's thermal regime and zooplankton community are well studied (Arhonditsis et al. 2004; Winder & Schindler 2004; Hampton et al. 2006a,b; Winder et al. 2009), as is the basic biology of the major planktivores (Chigbu 2000; Beauchamp et al. 2004). The lake has a narrow littoral zone and so the limnetic zone is the primary habitat, dominated by three planktivorous fishes native to the region (juvenile sockeye salmon, three-spine stickleback *Gasterosteus aculeatus* and longfin smelt *Spirinchus thaleichthys*), and two native midwater piscivores (cutthroat trout, *O. clarki*, and northern pikeminnow, *Ptychocheilus oregonensis*). Densities of *Daphnia* spp. are significantly higher in the upper 10 m of the water column than at deeper depths during both thermally stratified and destratified seasons (Edmondson & Litt 1982); therefore, the DVM patterns of the different planktivores determine their access to zooplankton.

The overall objectives of this study were to (i) quantify variation in planktivore catch-per-unit-effort (CPUE) related to season, diel period and depth and (ii) evaluate whether the diel vertical distributions of planktivores are similar among species and size classes of fish in Lake Washington. We predicted that the armoured species (three-spine stickleback) would exhibit shallower distributions throughout the diel cycle than the un-armoured species (longfin smelt and sockeye salmon) because they may be more willing to accept predation risk. Additionally, we expected to observe shallower distributions throughout the diel cycle for the shorter-lived longfin smelt than the longer-lived and potentially more risk-averse, sockeye salmon. With respect to bioenergetic responses, we predicted that all three species should exhibit similar vertical distribution patterns during the cooler, weakly stratified period in April, but that juvenile sockeye salmon would occupy deeper, cooler strata than three-spine sticklebacks during the warmer fall stratification period. The range of near-optimal temperatures for juvenile sockeye salmon (≥90% maximum growth rate when food is unlimited at 8.0–19.5 °C; Beauchamp 2009) occurs over a cooler and broader range than the warmer, narrower range for three-spine sticklebacks (≥90% maximum growth rate when food is unlimited at 19.0–22.5 °C; Lefébure et al. 2011). Thermal optima are unknown longfin smelt, but the species is distributed farther to the south than sockeye salmon (i.e., to the Sacramento River), suggesting that they are more tolerant of warmer water. With respect to size within species, we evaluated the alternative hypotheses that (a) larger fish would forage more cautiously (i.e., move up in the water column later and be deeper overall) because they are already large and so have less to gain energetically, or (b) they would forage less cautiously because their larger size makes them less vulnerable to gape-limited visual predators.

Methods

Study site

Lake Washington is 32.2 km long, averages 2.5 km wide and has a maximum depth of 66 m. Thermal stratification in the lake begins in March and April, is fully established by late June–early July and persists through October, after which decreasing temperatures and wind destratify the lake through winter. From 1998 to 2010, surface temperatures (0–2 m) in April (spring) averaged 11.0 °C and bottom temperatures (52–54 m) averaged 7.3 °C (Fig. 1). October (fall) temperatures averaged 15.4 °C at the surface and 8.4 °C at the bottom. Dissolved oxygen levels during our study remained >5 mg·l^{-1} throughout the water column, except in some years during August–November when localised benthic levels of 3–5 mg·l^{-1} were recorded at 50–60 m depths (King County Department of Natural Resources, WA, unpublished data).

The primary crustacean zooplankton species in the lake include the cladoceran *Daphnia pulicaria* and the copepods *Cyclops bicuspidatus*, *Leptodiaptomus ashlandi* and *Epischura nevadensis*. *D. pulicaria* typically achieve moderate to high densities (5–35 organisms per l) from mid-May through November but are often below detection levels during winter and early spring (Hampton et al. 2006a,b). Copepod densities during winter and early spring are highly variable among years with either *C. bicuspidatus* or *L. ashlandi* predominating in the zooplankton assemblage (4–30 organisms per l for the predominant species; Beauchamp et al. 2004; Winder et al. 2009). In general, the dominant zooplankton (i.e., *D. pulicaria*) do not vertically migrate and are most dense in the upper 10 m of the water column and very scarce below 20 m, regardless of season (Edmondson & Litt 1982).

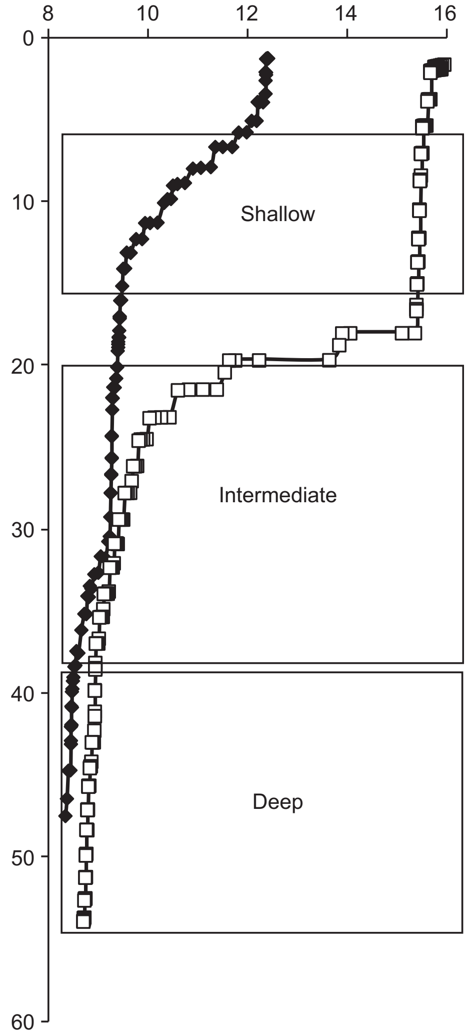

Fig. 1. Spring (April, solid diamonds) and fall (October, open squares) water temperature profiles from the sampling site in Lake Washington in a typical year (2005). Rectangles indicate the modal depth bins where fish were sampled.

Fish sampling

From 1997 to 2011, sampling was conducted in the central basin of Lake Washington, east of Sand Point in water *ca.* 50 m deep from 14 to 26 April and 11 to 29 October. These months incorporate several ecological patterns. In April, juvenile sockeye salmon are present in two age classes, age-0 [fry, ca. 30–50 mm fork length (FL)] and age-1 (fish *ca.* 110–130 mm FL that will migrate to sea later that spring; Fig. 2). Longfin smelt are present as age-1 fish (*ca.* 60–90 mm FL), because the age-2 fish have already spawned in rivers and died by this time of year while young-of-the-year have not yet recruited to the lake. In October, age-0 sockeye salmon (*ca.* 100–120 mm FL) are the only age class present, but both age-0 (*ca.* 40–60 mm FL) and age-1 (90–110 mm FL; Fig. 2) longfin smelt are present. Catches of limnetic three-spine sticklebacks are low in April because they breed in the littoral zone in late spring, but they are vulnerable to trawling in fall. In addition to these fish community dynamics, April and October present contrasts in thermal regime (cooler and weakly stratified in April; warmer and strongly stratified in October (Fig. 1)) without dramatic differences in overall prey availability. Zooplankton sampling from 25 m to the surface in the afternoon and at night on each date when fish were sampled revealed mean densities of 17.2 organisms L^{-1} in spring and 13.3 in fall. The dominant taxa were *D. pulicaria*, *C. bicuspidatus*, *Bosmina* sp., *Epischura* sp. and *L. ashlandi* (T.P. Quinn, unpublished data). *D. pulicaria* were proportionally less abundant in April, although this varied among years. Independent sampling farther south in the lake revealed similar patterns. The mean depth-stratified densities (±2 SE) of edible crustacean zooplankton during 2000–2007 were the following: $32.6 \pm 20.0\ l^{-1}$ in 0–10 m and $19.6 \pm 8.9\ l^{-1}$ in 10–20 m during April (1% *Daphnia*) versus $16.4 \pm 3.6\ l^{-1}$ in 0–10 m and $11.3 \pm 2.1\ l^{-1}$ in 10–20 m during October (31–38% *Daphnia*; D.E. Schindler, University of Washington, unpublished data).

Fish were captured using a Kvichak midwater trawl from 1997 to 2011, deployed for 15 min at three depths from mid-afternoon to night (Table 1). The net, held open by two horizontal metal bars, had a 2.5 m × 2.5 m cross-section and mesh decreasing from 76- to 2-mm knotless mesh in the cod end. Diel

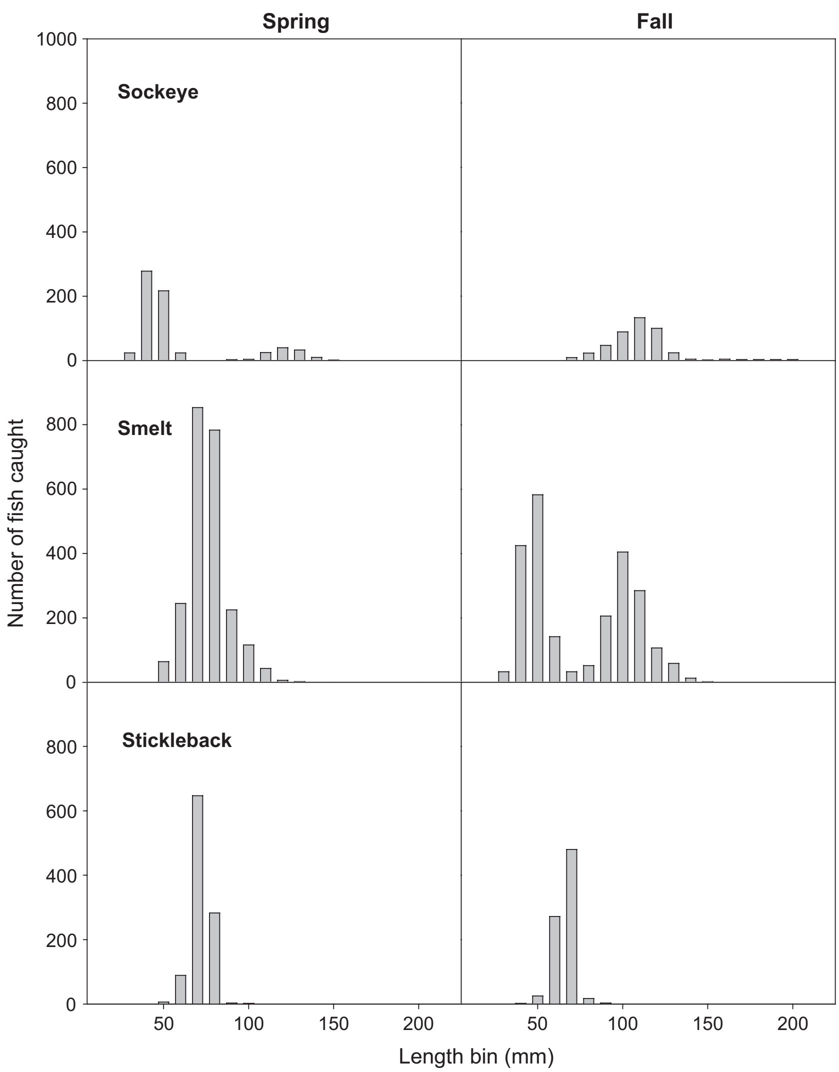

Fig. 2. Length frequency histograms for the three planktivore species sampled in Lake Washington in spring (April) and fall (October), pooling all samples from 1997 to 2011.

Table 1. Midwater trawl effort from 1997 to 2011, expressed as minutes towed (numbers of tows in parentheses) categorised by season, depth and period of the day.

		Total trawl minutes (N tows)		
Season	Depth category	Day	Dusk	Night
Spring	Shallow	679 (46)	317 (21)	151 (10)
	Intermediate	668 (45)	245 (16)	73 (5)
	Deep	811 (54)	226 (15)	105 (7)
Fall	Shallow	200 (14)	75 (5)	276 (19)
	Intermediate	247 (17)	46 (3)	293 (20)
	Deep	285 (20)	86 (6)	237 (16)

periods were categorised as day (before sunset), dusk (sunset to 1.5 h after sunset) and night (>1.5 h after sunset). Trawl depths were categorised as shallow (6–15 m), intermediate (20–38 m) and deep (38–54 m; depths shown in Fig. 1). Thermal exposure for fish averaged 9.5–12.0 °C in spring versus 15.5 °C in fall at shallow depths, 9.5 °C in spring versus 10–12 °C in fall at intermediate depths, and 8.5 °C in spring versus 9.0 °C in fall at deep depths. All captured fishes were counted in the field and measured to the nearest millimetre (FL) except in 2 years, when very large catches of age-0 longfin smelt were subsampled for length.

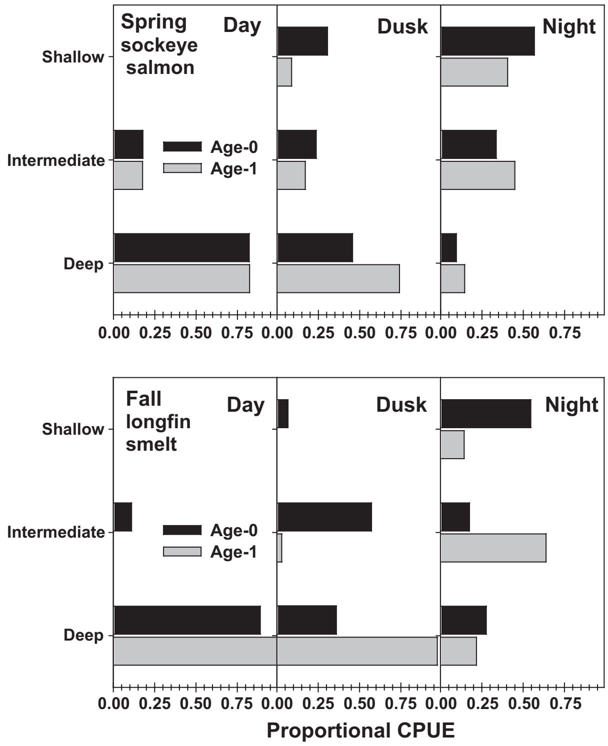

Fig. 3. Diel vertical distributions of age-0 and age-1 sockeye salmon in the spring (top) and longfin smelt in the fall (bottom). Catch-per-unit-effort (CPUE, N·min^{-1}) was standardised by the total CPUE for each age class × diel period.

Catch analysis

To examine the general patterns in planktivore distribution, we calculated the mean number of fish caught per minute trawled across years for discrete depth × diel × season sampling cells. Catch data were normalised in this manner to account for slight variation in tow time and differences in effort across sampling cells (Table 1). We used generalised linear models (GLMs) to determine the relative importance of depth, diel period and season in explaining variation in planktivore CPUE for individual species. Model parameter coefficients were used to support species-specific patterns in diel vertical distribution. We then examined the CPUE data graphically, to describe differences in diel vertical distribution patterns among species and ages.

Many tows caught no fish; therefore, we used a delta approach to model CPUE because it is appropriate for zero-inflated data (Helser et al. 2004; Maunder & Punt 2004). CPUE was modelled as a function of environmental variables in a two-stage process. First, the probability of capturing a species (i.e., frequency of occurrence in tows) was estimated using a GLM with a binomial error distribution. Then, the CPUE for nonzero tows was modelled using a negative binomial GLM with a log-link function. Thus, the overall CPUE may be determined as the product of the probability of a nonzero catch and the expected CPUE, given that the catch was nonzero. Models were fit separately to data for the three species. Age-0 and age-1 fish were combined in the analyses due to small sample sizes for individual age classes; however, we present graphical summaries of age-specific diel vertical distributions (Fig. 3).

Eight GLMs were evaluated for each species, including the null model (intercept only) and all possible combinations of three discrete predictor variables: depth (shallow, intermediate and deep); diel period (day, dusk and night); and season (fall and spring). Models provided reasonably good fits to the data; estimated dispersion parameters ranged from 0.60 to 1.43, indicating little evidence of over- or under-dispersion (Helser et al. 2004). Additionally, diagnostic plots of deviance residuals versus fitted values from the full models showed constant variance, and half-normal plots of the residuals showed no outliers (Faraway 2006).

For each stage of the analytical process described earlier, we compared the eight candidate models using Akaike's information criteria, bias-corrected for small sample size (AICc), which balances model complexity (number of estimated parameters) with the goodness of fit, as determined by likelihood (Burnham & Anderson 2002). The ΔAICc was calculated for each model as its AICc minus the lowest AICc across all models; by convention, models with ΔAICc within two of the minimum AICc are classified as performing equivalently to the best approximating model (Burnham & Anderson 2002). We calculated the Akaike weight (w_i) for each model, interpreted as the weight of evidence (probability) that model i is the best approximating model from among the set of candidate models (Johnson & Omland 2004). As w_i approaches one, the weight of evidence in favour of model i increases (Burnham & Anderson 2002). The relative importance of each predictor variable j (w_j) was estimated by summing w_i across all models in the set that included variable j; the closer w_j is to 1, the more important the variable in predicting the response across all models (Burnham & Anderson 2002).

Results

Longfin smelt were the most abundant species caught by midwater trawling during spring and fall sampling periods (71.7% of all fish caught), followed by three-spine stickleback (18.6%) and sockeye salmon (9.7%). Season, depth and diel period were important predictors of frequency of occurrence and density (nonzero CPUE) for all three species, based on their inclusion in the set of best approximating models (Table 2). For all species, observed spatial–temporal patterns in CPUE (Figs 4 and 5) were supported by coefficient values from best-fit models; coefficient estimates from the full models indicate the magnitude and direction of the effect of each parameter on planktivore CPUE (Table 3). For example, slope coefficients estimated from the full model for sockeye (Table 3) increased from day to night periods; this mirrors the graphical trend in sockeye CPUE (Fig. 4). Qualitative differences in patterns of age-specific CPUE were apparent in spring for sockeye salmon and in fall for longfin smelt. Generally, younger fish were caught in larger proportions higher in the water column during dusk and night periods than older conspecifics (Fig. 3).

Juvenile sockeye salmon demonstrated a seasonal shift in diel vertical distribution patterns. During spring, CPUE was highest in deep water during the day, intermediate depths at dusk and shallow depths at night (Fig. 4), whereas in the fall the highest CPUE was in deep water across all diel periods (Fig. 5). In both seasons, the frequency of occurrence and density increased dramatically from afternoon to dusk and night. Variation in sockeye salmon occurrence was related strongly to season, depth and diel period (w_j = 1.0); however, diel period and depth were more important than season in dictating the density of sockeye (Table 4). Sockeye salmon were encountered less frequently in fall surveys than in the spring but were captured in similar densities (nonzero CPUE) across seasons (Table 3).

Table 2. Diagnostic statistics for generalised linear models describing the relationships between catch-per-unit-effort (CPUE) and environmental factors. CPUE was modelled using a two-stage process, first estimating the probability of capturing a species (a) and then modelling the CPUE given that the species was caught (b). AICc is Akaike's information criteria bias-corrected for small sample size, ΔAICc is the AICc for each model minus the lowest AICc from all possible models, and w_i is the model Akaike weight.

	(a) Frequency of occurrence			(b) CPUE, nonzero tows		
	AICc	ΔAICc	w_i	AICc	ΔAICc	w_i
Sockeye salmon						
Model parameters						
Depth + Diel + Season (full model)	332.0	0.0	1.00	821.9	2.2	0.22
Depth + Diel	367.1	35.0	0.00	819.7	0.0	0.67
Depth + Season	423.8	91.7	0.00	838.2	18.6	0.00
Depth	431.5	99.5	0.00	849.2	29.5	0.00
Diel + Season	380.6	48.6	0.00	825.4	5.7	0.04
Diel	406.4	74.4	0.00	824.1	4.4	0.07
Season	449.0	116.9	0.00	844.9	25.2	0.00
Intercept (null model)	455.2	123.2	0.00	853.1	33.4	0.00
Longfin smelt						
Model parameters						
Depth + Diel + Season (Full model)	303.0	0.0	0.98	1821.1	0.0	0.47
Depth + Diel	310.9	8.0	0.02	1834.3	13.3	0.00
Depth + Season	404.6	101.6	0.00	1825.1	4.1	0.06
Depth	431.2	128.2	0.00	1854.9	33.9	0.00
Diel + Season	349.3	46.3	0.00	1821.2	0.1	0.44
Diel	357.2	54.2	0.00	1832.3	11.3	0.00
Season	428.4	125.4	0.00	1826.3	5.3	0.03
Intercept (Null model)	453.8	150.8	0.00	1855.4	34.3	0.00
Three-spine stickleback						
Model parameters						
Depth + Diel + Season (Full model)	416.3	0.9	0.29	1028.0	2.0	0.26
Depth + Diel	415.4	0.0	0.46	1026.0	0.0	0.70
Depth + Season	464.6	49.3	0.00	1032.2	6.2	0.03
Depth	464.1	48.7	0.00	1034.6	8.6	0.01
Diel + Season	418.6	3.2	0.09	1062.6	36.6	0.00
Diel	417.5	2.1	0.16	1063.3	37.3	0.00
Season	463.6	48.3	0.00	1074.5	48.5	0.00
Intercept (null model)	463.1	47.7	0.00	1076.6	50.6	0.00

Variation in longfin smelt occurrence and density were related strongly to season and diel period (w_j = 0.91–1.00) and, to a lesser extent, depth (w_j = 0.53–1.0; Table 4). Longfin smelt demonstrated distinct DVM patterns during both spring and fall, with CPUE increasing in intermediate and shallow depths from day to night periods (Figs 4 and 5). Smelt were encountered more frequently and captured in higher densities in fall than in spring (Table 3).

Depth and diel period were more important than season in dictating the occurrence and density of three-spine stickleback (Table 4). The highest densities of three-spine stickleback occurred in shallow depths during all diel periods in the spring (Fig. 4) and at night in the fall, but they were captured in very low densities at all depths during daylight and dusk in the fall (Fig. 5).

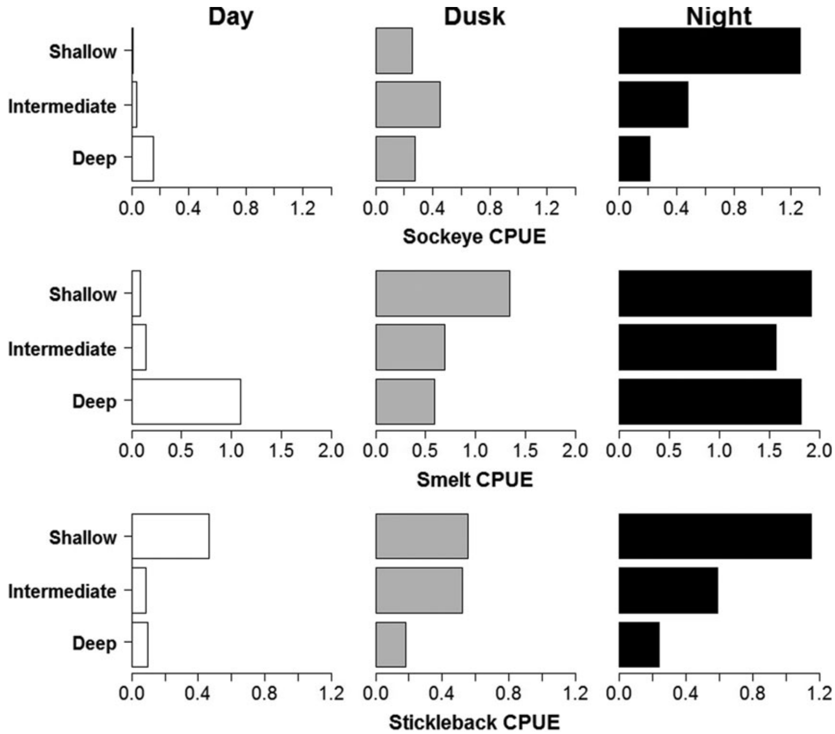

Fig. 4. Spring (April) depth distribution of sockeye salmon, longfin smelt and three-spine stickleback during day, dusk and night periods. Mean catch-per-unit-effort (CPUE, N·min^{-1}) is shown for all sampling years combined (1997–2011).

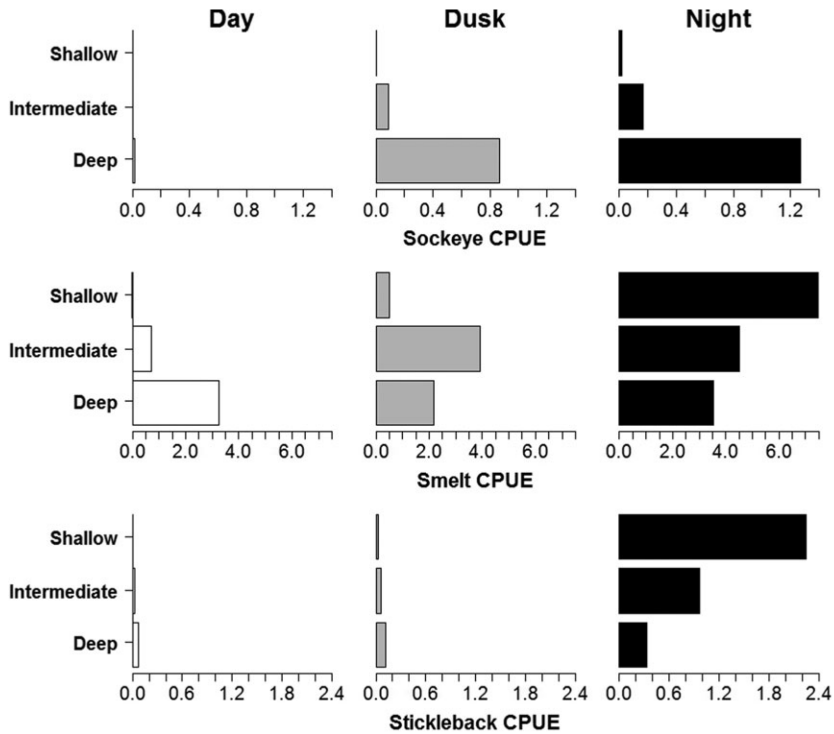

Fig. 5. Fall (October) depth distribution of sockeye salmon, longfin smelt and three-spine stickleback during day, dusk and night periods. Mean catch-per-unit-effort (CPUE, N·min^{-1}) is shown for all sampling years combined (1997–2011).

In summary, CPUE data provided evidence of DVM from deep water during the day to shallow water at night for all planktivores, but the strength of this distributional pattern and consistency between seasons varied among species. Sockeye salmon demonstrated a strong DVM during the spring, but remained at highest densities in deep water across diel periods during the fall. Longfin smelt exhibited DVM in both seasons and were more evenly distributed throughout the water column at night than the other species. Three-spine stickleback also showed increasing densities in shallow waters from day to night periods during both seasons, but were generally more abundant in shallow water across all diel periods.

Table 3. Parameter estimates from generalised linear models describing the (a) frequency of occurrence and (b) nonzero catch-per-unit-effort (CPUE) for three species. Coefficients (SE) are shown for the full model (Diel + Depth + Season).

	(a) Frequency of occurrence	(b) CPUE, nonzero tows
Sockeye salmon (full model)		
Intercept	−1.05 (0.41)	−1.04 (0.21)
Season: Oct	−2.16 (0.41)	0.01 (0.24)
Diel: Day	−2.62 (0.40)	−0.93 (0.24)
Diel: Night	0.69 (0.46)	0.47 (0.23)
Depth: Shallow	−1.54 (0.38)	0.44 (0.27)
Depth: Deep	0.99 (0.33)	0.64 (0.21)
Longfin smelt (full model)		
Intercept	−1.02 (0.44)	−0.22 (0.23)
Season: Oct	1.05 (0.34)	0.83 (0.20)
Diel: Day	−2.77 (0.43)	0.21 (0.24)
Diel: Night	0.93 (0.65)	0.74 (0.26)
Depth: Shallow	−0.99 (0.38)	0.52 (0.25)
Depth: Deep	1.52 (0.36)	0.33 (0.22)
Three-spine stickleback (Full model)		
Intercept	−2.28 (0.32)	−0.64 (0.26)
Season: Oct	−0.30 (0.28)	−0.14 (0.25)
Diel: Day	−1.38 (0.30)	−0.04 (0.27)
Diel: Night	0.69 (0.39)	0.86 (0.30)
Depth: Shallow	−0.11 (0.30)	0.84 (0.26)
Depth: Deep	0.57 (0.30)	−0.85 (0.26)

Table 4. Parameter Akaike weights (w_j) calculated from all candidate generalised linear models, describing the relationships between catch-per-unit-effort (CPUE) in biannual trawl surveys and environmental factors. CPUE was modelled using a two-stage process, first estimating the probability of capturing a species (a) and then modelling the CPUE given that the species was caught (b).

	(a) Frequency of occurrence	(b) CPUE, nonzero tows
Parameter	w_j	w_j
Sockeye salmon		
Depth	1.00	0.89
Diel	1.00	1.00
Season	1.00	0.26
Longfin smelt		
Depth	1.00	0.53
Diel	1.00	0.91
Season	0.98	1.00
Three-spine stickleback		
Depth	0.75	1.00
Diel	1.00	0.96
Season	0.38	0.29

Discussion

Midwater trawl data from Lake Washington demonstrated species-specific variation in the vertical distribution patterns of three planktivores across season and diel periods. The three species differed from each other, and in general, the hypotheses proposed for species-specific variation in DVM were supported. The DVM indicated by the sockeye salmon data was consistent with that of prior work on Lake Washington (Eggers 1978) and elsewhere (Levy 1987; Scheuerell & Schindler 2003) on this species. Sockeye salmon reside in lakes for the first year or two of their lives, followed by migration to sea for the majority of their growth prior to return for spawning. In general, they grow slowly, as indicated by their smaller size at age when leaving freshwater compared with coho salmon, *O. kisutch*, a stream-rearing species, and smaller size for their age at sea than other Pacific salmon (Quinn 2005). In Lake Washington, age-0 sockeye salmon feed and grow much slower during their first months in the lake (Beauchamp et al. 2004) than sympatric lake-rearing Chinook salmon (Koehler et al. 2006). Where sympatric with pink salmon, *O. gorbuscha*, in lakes, sockeye salmon grow slower as well (Robins et al. 2005), and they seem to be generally unaggressive and risk-averse (Hoar 1954; Hutchison & Iwata 1997). Their nocturnal use of surface waters during spring was advantageous for growth, given the size and feeding rates exhibited by age-0 sockeye and to a lesser degree for the age-1 smolts (Beauchamp et al. 2004). In contrast, their strong avoidance of shallow strata during fall, when growth was insensitive to the range of temperatures available in deep (~9 °C) through shallow (*ca.* 15–16 °C) depths (Beauchamp 2009), was more consistent with predator avoidance.

There is less information on DVM by three-spine sticklebacks than by sockeye salmon, but DVM was reported in the Baltic Sea by Jurvelius et al. (1996) and Iliamna Lake, Alaska, by Quinn et al. (2012). In Alaska, significant numbers of sticklebacks were caught at the surface during the day, and their vertical shift in distribution was relatively subtle. In contrast, daytime catch rates of sockeye salmon at that lake were negligible compared with night-time catches (T.P. Quinn, unpublished data). Compared with sockeye salmon, three-spine sticklebacks are armoured (though still subject to predation from birds and fishes; Kitano et al. 2008), have a 1-year lifespan in Lake Washington (Eggers et al. 1978), and warmer optimal temperature for growth (Lefébure et al. 2011). During both spring and fall, the shallow stratum offered higher growth benefits for three-spine sticklebacks than either the intermediate or deep strata. These features likely all contributed to their greater proximity to the surface. Longfin smelt appeared to be intermediate between sockeye salmon and three-spine sticklebacks in their use of the epilimnion and extent of DVM. Like sockeye salmon, they lack defensive structures and are readily consumed by cutthroat trout in the lake (Beauchamp et al. 1992; Nowak et al. 2004), but their lifespan is much shorter, typically maturing at age-2 (Moulton 1974; Chigbu 2000).

Our age-specific samples of sockeye salmon in spring and longfin smelt in fall were insufficient for the rigorous statistical comparisons needed to test the two hypotheses concerning size effects on DVM, so these results should be interpreted cautiously. However, the general patterns (Fig. 3) indicated greater proximity to the surface among the young-of-the-year, especially in longfin smelt. These fish would be more vulnerable to predation on the basis of size than the yearlings, and the use of the surface waters suggests that foraging to achieve growth was more important than predation risk. However, two features of the biology of smelt complicate this interpretation. First, the young-of-the-year are nearly transparent and so may be less vulnerable to visual predators than might be expected based on the size alone. In addition, the larger smelt feed more heavily on *Neomysis* than do smaller smelt (Chigbu and Sibley 1998), and *Neomysis* are closely associated with the bottom during the day, whereas zooplankton are primarily in the epilimnion. This difference in the locations of focal prey may also affect the vertical distributions of the age groups. Recently, Busch & Mehner (2012) reported earlier and more rapid ascent at dusk by smaller coregonids compared to larger ones, so the size-specific DVM patterns we saw may be genuine but further sampling is needed.

For all three species across all depths and seasons, there was a large disparity in CPUE among diel periods (lowest during daylight, intermediate at dusk and highest at night). Although light-mediated gear avoidance likely contributed to this disparity, this pattern was also observed in unbiased seasonal and diel hydroacoustic surveys (Beauchamp et al. 1999; Mazur & Beauchamp 2006). This disparity could be explained by schooling or a strong benthic association during daylight followed by partial or full dispersal into the water column at dusk and night. Our net was not designed to sample on the bottom, so close proximity to the bottom would greatly reduce vulnerability to the gear. Daylight schooling can be difficult to detect, much less quantify, by either small midwater trawls or narrow beam hydroacoustics. Nonetheless, occasional schools have been detected in the upper 10 m of the lake during hydroacoustic surveys in October (Mazur 2004; D.A. Beauchamp, unpublished data), and a single catch of nearly 17,000 three-spine sticklebacks was encountered when fishing at 15 m during daylight in October 2001 as well (Overman et al. 2006).

The seasonal and diel vertical distribution patterns of the three planktivores may reflect trade-offs between antipredation behaviour and bioenergetic benefits from behavioural thermoregulation. The low densities of nonschooling planktivores in the upper water column during daylight in both seasons, except for the armoured three-spine sticklebacks in spring, suggested that predator avoidance was a high priority during high-light periods. The depth distribution patterns during dusk were often intermediate between day and night periods and could reflect either a critical feeding period during an antipredation window (e.g., Eggers 1978; Clark & Levy 1988; Scheuerell & Schindler 2003) or simply a transition from daylight to nocturnal distributions. Strong crepuscular feeding peaks were reported for longfin smelt (Dryfoos 1965) and juvenile sockeye salmon (Doble & Eggers 1978) in Lake Washington during the 1960s and early 1970s, before the emergence of *Daphnia* as the predominant zooplankter in the mid-1970s.

The depth distributions at night likely reflected thermoregulation, because darkness should minimise predation risk and inhibit feeding by the planktivores. The juvenile sockeye salmon moved into the epilimnion at night in spring, where the warmer temperatures offered a bioenergetic growth benefit. However, when the thermal benefit was neutral in fall, they remained in deep water at night. In contrast, the epilimnetic temperatures during both spring and fall were beneficial for growth of three-spine stickleback, and presumably for longfin smelt, and the highest catches of both species were in shallow depths at night during both seasons. Although little is known about the thermal preferences of longfin smelt, their optimal temperature is likely higher than for sockeye salmon, based on the much more southerly range of anadromous populations (Scott & Crossman 1973) and their generally shallower distribution in stratified lakes (Enzenhofer & Hume 1989; Chigbu et al. 1998). During peak thermal stratification in July–September, the 18–23 °C average epilimnetic temperatures in Lake Washington (Arhonditsis et al. 2004) would markedly reduce the growth of sockeye salmon, but optimise the growth of three-spine stickleback and possibly of longfin smelt.

The seasonal differences in DVM among species have implications for their vulnerability visually feeding limnetic predators. Using telemetry data on cutthroat trout (Nowak & Quinn 2002) and hydroacoustic data on nonschooling planktivores, a visual detection foraging model predicted that in spring, most predator–prey encounters would occur in the upper 12 m during all diel periods but rates were highest at dusk in the upper 6 m (Mazur & Beauchamp 2006). In fall, most predator–prey encounters would occur in the upper 21 m of the water column during all diel periods, with slightly higher maximum encounter rates in the upper 6 m at night (Mazur & Beauchamp 2006). These predicted encounter rates suggest that the planktivores were only vulnerable to predation in the shallow stratum. Thus in April, a larger fraction of the three-spine stickleback population was vulnerable to encounters with predators than in fall, followed by longfin smelt, and then sockeye salmon. In October, these species displayed the same ordering in terms of predicted encounter rates with predators, but sockeye salmon were much less vulnerable than in the spring. Indeed, during 1995–2000, juvenile sockeye salmon represented larger fractions of the limnetic cutthroat trout diets in spring than in the fall, whereas longfin smelt contributed less to trout diets in spring than in fall, and sticklebacks contributed considerably less during any season for data spanning 1984–2000 (Beauchamp et al. 1992; Nowak et al. 2004). Following the recent fivefold increase in three-spine sticklebacks (Overman & Beauchamp 2006; Overman et al. 2006), they represented larger fractions of cutthroat trout diets (but low prey electivity indices) during spring and fall, while similar patterns in seasonal contributions by the other species persisted (D.A. Beauchamp, unpublished data).

In addition to the patterns documented by this study for the three planktivore species in Lake Washington, it offers broader implications for the DVM phenomenon and applied lake ecology. As noted by Piet & Guruge (1997), vertical distribution and DVM affect many aspects of community ecology in lakes, including the influences of non-native species. Assessment of these ecological interactions is greatly complicated by the variation in species-specific DVM patterns with season and size, and changing community composition at different trophic levels as species invade lakes and cascading effects occur. Lake Washington has had a particularly interesting and well-studied history of sequential effects of natural and human-related processes (Edmondson 1994; Winder et al. 2009), but it is certainly not unique. Modelling efforts directed at the conservation of species at risk and control of unwanted invasive species may hinge in part on complex trophic interactions affected by DVM patterns.

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Spatial perspective for delta smelt: a summary of contemporary survey data

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We utilized recently available data from the 20-mm Tow-Net and Spring Kodiak Trawl, together with other Interagency Ecological Program and regional monitoring programs, to provide a comprehensive description of the range and temporal and geographic distribution of delta smelt (*Hypomesus transpacificus*) by life stage within the San Francisco Estuary, California. Within 21 sampled regions we identified 289,401 survey events at 624 monitoring stations. Delta smelt were observed at 430 stations (69%) in an area from northern San Francisco Bay in the west, to the confluence of the Sacramento and Feather rivers in the north, and to the disjunction of Old and San Joaquin rivers in the south, an area of approximately 51,800 ha. Delta smelt were observed more frequently and at higher densities (at all life stages) near the center of their range, from Suisun Marsh down through Grizzly Bay and east Suisun Bay through the Confluence to the Lower Sacramento region, and into the Cache Slough region. Delta smelt larvae were observed in the San Francisco Estuary from March through July, sub-juveniles in April through August, juveniles in May through December, sub-adults in September through December, and pre-spawning and spawning adults in January through May. This comprehensive review provides managers and scientists an improved depiction of the spatial and temporal extent of the delta smelt throughout its range and lends itself to future analysis of delta smelt population assessment and restoration planning.

Key words: Delta smelt, distribution, *Hypomesus transpacificus,* spatial analysis, life stage, observed presence, Sacramento River delta, San Francisco estuary, San Joaquin River delta

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The delta smelt (*Hypomesus transpacificus*) is a small, euryhaline fish endemic to the San Francisco Estuary of California (Estuary). Once the most abundant fish captured in trawl surveys conducted in the Sacramento-San Joaquin Delta (Stevens and Miller 1983, Moyle and Herbold 1989, Stevens et al. 1990) the species suffered a reduction in numbers sufficient to justify threatened listing in 1993 under both the federal and California Endangered Species Acts (ESA). Similar to other Estuary fish species, delta smelt experienced a further decline beginning in 2000 (Sommer et al. 2007) and was listed as endangered under the California ESA in 2009. As a result, the delta smelt has received considerable attention as one of four pelagic fish species experiencing declines in abundance (see Armor et al. 2005, Baxter et al. 2008, Feyrer et al. 2010, Mac Nally et al. 2010, Thompson et al 2010).

Despite the critical condition of the delta smelt population, a geographical summary of its distribution by life stage has not been clearly defined. Conservation planning under federal and state statutes requires spatial resolution (Tracy et al. 2004, Carroll et al. 2006). Distributional summaries of delta smelt were provided in the formal notice conferring its federal protection (USFWS 1993), subsequent designation of critical habitat (USFWS 1994), and completion of conservation planning documents (see USFWS 1996, 2003; California Resources Agency 2005, 2007). However, these sources lack a spatial depiction of where and when delta smelt have been observed. In a California Department of Fish and Game (CDFG) status review (Sweetnam and Stevens 1993), the historical range for the species was described using life history descriptions from existing literature. The United States Fish and Wildlife Service (USFWS 1996) has also provided delta smelt distribution maps using data from the Fall Midwater Trawl, and the CDFG has created interactive maps using individual surveys for some of its monitoring programs (see http://www.dfg.ca.gov/delta). However, to our knowledge, no effort has been made to map the range of delta smelt using all available sampling data or to summarize distribution of delta smelt by life stage.

The distribution of at-risk species is important information for conservation planning. Nearly all ecological data necessary to develop effective resource management agendas have attributes that can be portrayed spatially. Distributional data in the forms of species range maps, breeding surveys, and biodiversity atlases have become tools used commonly in analyses of species-environment relationships (Brundage and Meadows 1982, Flather et al. 1997, Ferrier 2002, Ceballos and Ehrlich 2006, Hulbert and Jetz 2007, Cabeza et al. 2010) and for conservation and management plans for endangered or threatened species, environmental risk assessment, and for calculating responses of at-risk species under future management scenarios (Dormann et al. 2007). Conservation and monitoring programs designed to assess the effectiveness of those actions frequently are site-specific, and are more likely to be successful when spatial elements of planning are well understood (Tracy et al. 2004, Carroll et al. 2006).

Delta smelt are vulnerable to many environmental stressors (USFWS 1993, Moyle 2002, Baxter et al. 2008, Healey et al. 2008), and the significance of a particular stressor may change in relation to its manifestation or proximity to the species (Tong 2001, Armor et al. 2005). Furthermore, delta smelt are migratory (Bennett et al. 2002, Dege and Brown 2004, Hobbs et al. 2007, Sommer et al. 2011), and habitat requirements differ by life stage. An understanding of where delta smelt are distributed throughout their range at each life stage may provide insight about habitat attributes important for each life stage and, therefore, help inform strategies as managers undertake habitat restoration actions.

The purpose of this paper is to present a geographic summary of publicly available data on the distribution of delta smelt by life stage. With initiation of the 20-mm Tow-Net in 1995 and the inception of the Spring Kodiak Trawl in 2002, the CDFG and other agencies that comprise the Interagency Ecological Program (IEP) provide data on the distribution of delta smelt at various life stages. Using data from these surveys and a variety of publicly available sources, we refined knowledge of the spatial extent and distribution of delta smelt in the Estuary. Specifically, we reviewed all available data on observed presence and density of delta smelt from a spatial perspective in an effort to document (1) the observed geographic extent of delta smelt, and (2) the spatial and temporal distributions for identified life stages.

Methods

Study area.—The Estuary is the largest of its kind along the U.S. Pacific Coast (approximately 1,235 km^2, Rosenfield and Baxter 2007; Figure 1). Formed by the confluence of the Sacramento and San Joaquin watersheds with San Francisco Bay, the Estuary drains an area of approximately 163,000 km^2 (40% of California's surface area; van Geen and Luoma 1999, Sommer et al. 2007) that stretches from the upstream limits of the Sacramento River in the north to the mountain tributary streams of the San Joaquin River in the south (Moyle 2002, Sommer et al. 2007). The Estuary is brackish and tidally influenced through its connection to San Francisco Bay, and is an example of an inverted river delta (whereby the narrow end of the delta emerges on the seafront and the wide end is located further inland), one of only a few existing worldwide. The water bodies east of the Sacramento River confluence with the San Joaquin River are commonly referred to as the Sacramento-San Joaquin Delta (Delta). The Delta is the upstream portion of the Estuary where riverine freshwater tidally washes back and forth within leveed channels, roughly between the cities of Sacramento, Stockton, Tracy, and Antioch. The Delta extends about 37 km east to west and 77 km north to south and includes parts of Sacramento, San Joaquin, Contra Costa, Solano, and Yolo counties (Moyle 2002, Lund et al. 2007).

To facilitate the spatial depiction of delta smelt, we grouped monitoring locations into Estuary regions (Table 1; Figure 1) based on preliminary work by Kimmerer (2009) and physical landmarks (e.g., bays, sloughs) (Figure 1). To distinguish areas with large-scale habitat differences (e.g., watershed drainages, confluences), we subdivided (1) the upper Sacramento River into two regions, differentiating the Ship Channel, Yolo Bypass, and Cache Slough from the rest of the upper Sacramento River; (2) San Pablo Bay into western and eastern regions; and, (3) the South Delta into the South Delta and upper San Joaquin River. We also added a Sacramento Valley region (covering upstream from the confluence of the Sacramento and American rivers), two Napa River regions (split between the lower and upper), and a San Francisco Bay region.

IEP monitoring programs.—The CDFG and USFWS, as members of the IEP, have surveyed fish at a number of stations throughout the Estuary for several decades (Table 2, Figure 1). These monitoring programs include the 20-mm Tow-Net (20-mm), Summer Tow-Net (STN), Fall Midwater Trawl (FMWT), Bay Study Midwater Trawl (BMWT), Spring Kodiak Trawl (Kodiak), and Beach Seine (herein collectively referred to as the IEP monitoring programs). Each IEP monitoring program is conducted during a different season and sampling frequency (monthly or bi-weekly), and at a varying number of stations (30-113; Table 2). By employing different gears during different time periods, each monitoring

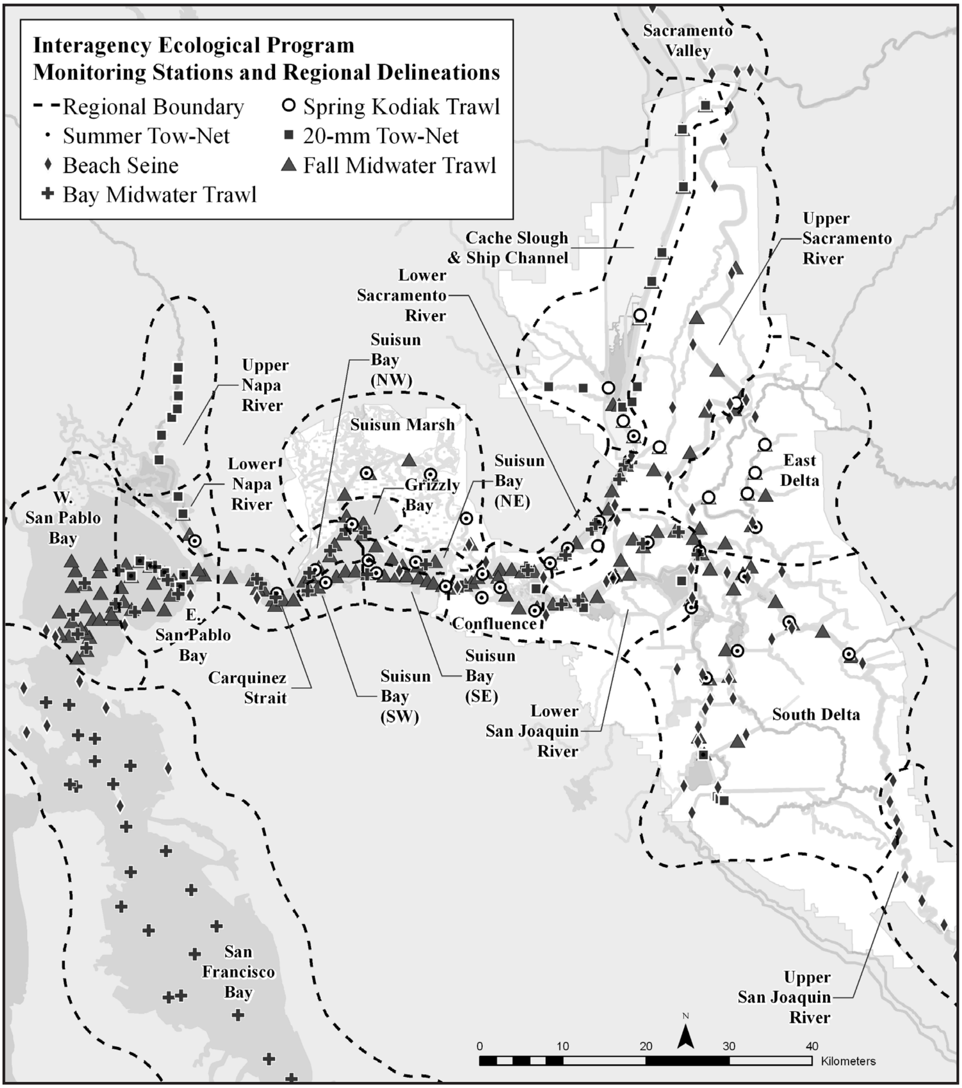

FIGURE 1.—Monitoring stations of Interagency Ecological Program surveys conducted in the San Francisco Estuary by the California Department of Fish and Game (Summer Tow-Net, Fall Mid-Water Trawl, Bay Mid-Water Trawl, Spring Kodiak Trawl, and 20-mm Tow Net) and the United States Fish and Wildlife Service (Beach Seine). Dashed lines indicate regional boundaries. The white area represents the legal Delta as set forth in the Delta Protection Act of 1959.

Table 1.—San Francisco Estuary sampling regions and associated stations by sample method. IEP monitoring programs are described in Table 2 and regional monitoring programs are described in Table 3. NS = not sampled and NI = no regional sampling identified.

	IEP Monitoring Programs						
Region	20-mm Tow-Net	Summer Tow-Net	Fall Midwater Trawl	Spring Kodiak Trawl	Bay Midwater Trawl	Beach Seine	Regional Monitoring
San Francisco Bay	NS	NS	NS	NS	20	7	NI
West San Pablo Bay	NS	NS	12	NS	5	3	NI
East San Pablo Bay	7	7	19	NS	5	2	NI
Lower Napa River	3	1	2	2	NS	NS	NI
Upper Napa River	7	NS	NS	4	NS	NS	NI
Carquinez Straight	1	1	7	1	2	NS	1
Suisun Bay Southwest	1	1	5	1	1	NS	1
Suisun Bay Northwest	1	1	5	1	2	NS	1
Suisun Bay Southeast	2	3	8	2	1	NS	2
Suisun Bay Northeast	2	1	5	2	1	NS	2
Grizzly Bay	1	1	4	1	2	NS	1
Suisun Marsh	3	3	5	5	NS	1	73
Confluence	5	4	10	4	2	1	8
Lower Sacramento River	4	3	4	4	3	NS	4
Upper Sacramento River	1	2	16	4	3	12	3
Cache Slough and Ship Channel	13	NS	3	5	NS	10	43
Lower San Joaquin River	6	4	12	6	5	4	6
East Delta	1	1	8	5	NS	5	29
South Delta	9	6	11	6	NS	18	12
Upper San Joaquin River	NS	NS	NS	NS	NS	16	NI
Sacramento Valley	NS	NS	NS	NS	NS	18	1
Total	67	39	136	53	52	97	187
Percent of Regions Represented	81%	71%	81%	76%	62%	57%	71%

Table 2.—Interagency Ecological Program monitoring programs that sample delta smelt: years and months surveyed, number of survey stations, and size of delta smelt captured for each monitoring program.

Monitoring Program (Agency)	Years	Sampling Period (Frequency)	No. of Stations	Captured Delta Smelt Lengths (mm)
Fall Midwater Trawl (CDFG)	1967-present	Sep-Dec[a] (Monthly)	53-113	> 30
Summer Tow-Net (CDFG)	1959-present[b]	Jun-Aug (Bi-Weekly)	~30	15 - 65
20-mm Tow-Net (CDFG)	1995-present	Mar-July (Bi-weekly)	41-49	5 - 60
Spring Kodiak Trawl (CDFG)	2002-present	Jan-May (~Bi-weekly)	30-40	> 50
Bay Midwater Trawl (CDFG)	1980-present[c]	All Year (Monthly)	52	> 30
Beach Seine (USFWS)	1977-present	All Year[d] (~Bi-weekly)	~40	> 30

[a]Survey continued through March during 1991-2001.

[b]Delta smelt were not measured or consistently enumerated until 1973.

[c]Delta stations added in 1991 and 1994.

[d]Since 1994. Before 1994 only January-March were consistently sampled each year.

program is selective for different sizes of delta smelt, and therefore different life stages (Table 2). The methods for the IEP monitoring programs have been described previously (Moyle et al. 1992, USFWS 2003, Bennett 2005), as have the merits of several resulting abundance indices (Bennett 2005).

Regional monitoring programs.—In addition to the IEP monitoring programs, numerous other monitoring programs are carried out by various governmental and non-governmental entities, and for a variety of purposes (Table 3). These programs utilize an assortment of gears including seining, electrofishing, and tow-nets. Some of these programs have been carried out for a decade or more. Collectively, they are referred to as regional monitoring programs throughout the remainder of this paper.

Table 3.—Regional monitoring programs sampling delta smelt: survey location, survey gear, project, study period, and data source.

Location	Survey Gear Used	Project	Study Period	Source
Cosumnes River	seine, electrofishing	Floodplain Monitoring	1998-2005	Moyle et al. 2007
Cosumnes River	light trap	Floodplain Monitoring	1999-2001	Crain et al. 2004
Cosumnes River	seine	Stream Evaluation	1990s-2000s	R. Titus[a]
Lower American River	rotary screw trap	Stream Flow and Habitat Evaluation Program	1990s-2000s	R. Titus[a] Snider and Titus 2000 Snider et al. 1998
Yolo Bypass	rotary screw trap, fyke net/trap, beach seine, purse seine	Yolo Bypass Study	1998-2005	CDWR[b]
Yolo Bypass	rotary screw trap, and egg and larval nets	Yolo Bypass Floodplain	1999-2002	Sommer et al. 2004
Sacramento Deep Water Shipping Channel	tow nets and trawl	20 mm, STN, FMWT	2009	Samii-Adib 2010
Suisun Marsh	beach seine, larval sled, midwater trawl, otter trawl	Suisun Marsh Fisheries Monitoring	1979-2005	UCD[c]
Lower Mokelumne River	seining, backpack electrofishing surveys, boat electrofishing surveys	East Fish Community Survey	1997-2004	Merz and Saldate 2005
Lower Mokelumne River	rotary screw trap	Mokelumne River Salmon and Steelhead Monitoring	1990-2009	EBMUD[d]
Lower Calaveras River	beach seine	Calaveras River Barrier Removal program	2010	T. Kennedy[e]
West Delta	beach seine	West Delta Survey	2005-2006	T. Kennedy[e]
North Delta	plankton net	North Bay Aqueduct Survey	1994-2004	CDFG
Upper San Francisco Estuary	plankton net	Smelt Larval Survey	2009 -2010	CDFG
South Delta	louvers	Central Valley Project	1955-present	CDFG
South Delta	louvers	State Water Project	1972-present	CDFG
Chipps Island	boat trawling	Chipps Island Midwater Trawl	1976-2008	USFWS
South-east Suisun Bay, Confluence of Sacramento & San Joaquin Rivers	sieve net	Mirant Power Plants	2006	IEP
South Delta	sieve net	Contra Costa Water District Intake Facility	1995-present	CDFG

[a]CDFG, personal communication
[b]California Department of Water Resources
[c]University of California, Davis
[d]East Bay Municipal District
[e]Fishery Foundation of California, personal communication

Observed geographic extent.—To identify the geographic extent of delta smelt, we utilized records taken from IEP and regional monitoring programs. We present all years of available data for each monitoring program (Tables 2 and 3). If delta smelt were detected at least once at any given monitoring location, they were designated as present at that site; otherwise they were designated as not observed. Because the detection probability for each type of survey gear is not available and each monitoring program is conducted at different sampling frequencies and levels of effort, we did not consider delta smelt to be absent from locations where the species was not observed (Pearce and Boyce 2006). Since our objective was to identify the range of delta smelt presence, and not to examine where delta smelt are absent, we did not further assess the likelihood of falsely identifying delta smelt as being absent at a given location.

We developed a boundary for the observed geographic extent of delta smelt by using a 1-km buffer around sites where delta smelt were observed, including all open water between points within the boundary (Graham and Hijmans 2006 for discussion of buffer size). We then calculated the surface area of all waters within the boundary.

We also examined the geographic distribution of sampling stations and sampling effort among the IEP and regional monitoring programs. We enumerated how many stations were sampled by each of the IEP monitoring programs and all the regional monitoring programs combined within each of the 21 identified regions, and calculated the percentage of regions sampled by each monitoring program.

Distribution by life stage.**—**Extending from the life history discussions of Moyle (2002) and Bennett (2005), we differentiated five separate delta smelt life stages: larvae,

Table 4.—Delineation of delta smelt life stages by the Interagency Ecological Program, fish size or reproductive stage, time periods, and years of available samples. 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net,

Life Stage	Monitoring Program	Life Stage Distinction	Time Period	Years of Data Used
Larvae	20-mm	<15 mm	Apr-Jun	1995-2009
Sub-juveniles	20-mm, STN	≥15,<30 mm	20-mm: Apr-Jul STN: Jun-Aug	1995-2009
Juveniles	20-mm, STN, FMWT	30-55 mm	20-mm: May-Jul STN: Jun-Aug FMWT: Sep-Dec	1995-2009
Sub-adults	FMWT	>55 mm	Sep-Dec	1995-2009
Mature Adults	Beach Seine, BMWT	>55 mm	Beach Seine: Dec-May BMWT: Jan-May	Beach Seine: 1995-2009 BMWT: 1995-2006
Mature Adults: Pre-spawning	Kodiak	Reproductive stages[a]: females 1-3; males 1-4	Jan-Apr	2002-2009
Mature Adults: Spawning	Kodiak	Reproductive stages[a]: females 4; males 5	Jan-May	2002-2009

[a]Gonadal stages of male and female delta smelt found in Spring Kodiak Trawl database were classified by California Department of Fish and Game following Mager (1986). Descriptions of these reproductive stages are available at: http://www.dfg.ca.gov/delta/data/skt/eggstages.asp

sub-juveniles, juveniles, sub-adults, and mature adults (Table 4). We chose a 15-mm total length as the cut-off between larvae and sub-juveniles because when delta smelt reach 16-18 mm their fins are more developed and their swim bladder is filled with gas, making them more mobile within the water column (Moyle 2002). We used 30 mm as the cut-off between sub-juveniles and juveniles because this size is associated with a change in feeding regime (Moyle 2002). We chose 55 mm as the cut-off between juveniles and sub-adult and mature adults because growth slows between 55 and 70 mm (with most of the available energy diverted to gonadal development [Radtke 1966, Erkkila et al. 1950]). Because maturation rate of captured delta smelt was reported for the Spring Kodiak Trawl, we used reproductive stage to further subdivide mature adults into pre-spawners and spawners. Reproductive stages 1 to 3 for females, and 1 to 4 for males, were classified as pre-spawning. Reproductive stages 4 in females, and 5 in males, were classified as spawning (J. Adib-Samii, CDFG, personal communication; additional information is available at: http://www.dfg.ca.gov/delta/data/skt/eggstages.asp).

We used data from the IEP monitoring programs to elicit information on the temporal and spatial distribution of life stages. For each life stage, we delineated a period of several months when delta smelt of that life stage often were observed. We excluded months when delta smelt were caught in very low numbers (<3% of the total for that life stage) because those data would have biased frequency of observation and observed density results downward. Where possible, we used data from multiple monitoring programs that sampled the same life stage at different months during the year (Table 4).

Although data are available for juveniles and adults back to 1967 (FMWT), we present only results from 1995 onward to compare life stage distributions during similar time periods; 20-mm Tow-Net surveys were first conducted in 1995, and provided data for larvae, sub-juveniles, and juveniles. Data from two monitoring programs were not available for the full period from 1995 to 2009: the Kodiak (2002-2009), and the BMWT (1995-2006), which after 2006 was adjusted to avoid high levels of delta smelt take (R. Baxter, CDFG, personal communication). We excluded supplemental samplings because such surveys were conducted for special purposes and were not always consistent with the protocol for the program (R. Baxter, CDFG, personal communication). To avoid introducing anomalies caused by the addition of new stations, we included only sampling stations that were sampled consistently (i.e., stations that were sampled ≥ 90% of the years).

We calculated the average annual frequency of delta smelt observation at consistently surveyed stations for each life stage in each region for all years as

$$P_{lrpy} = (S_{lrpy} / N_{rpy})(100) \tag{1}$$

where: P_{lrpy} is the percent of sampling events (i.e., a sample at a station) when delta smelt of life stage l were caught in region r during time period p and year y, S_{lrpy} is the number of sampling events in region r when delta smelt of life stage l were caught during time period p and year y, and N_{rpy} is the total number of sampling events in region r during time period p and year y. Next, the average annual frequency of delta smelt observation for each life stage and region was calculated as a simple average over all years.

We calculated the yearly observed density (Density; i.e. relative measure of abundance) of delta smelt for each life stage and region for all years by dividing the summed catches C of delta smelt for each life stage l, region r, time period p, and year y by the volume of water in cubic meters V that was sampled for each region and year, then multiplying by

10,000 to determine the catch per 10,000 m^3 of water for each life stage, region, and year as

$$Density_{lry} = (\Sigma C_{lry} / \Sigma V_{ry})\ (10000) \qquad (2)$$

Next, the average annual observed density for each life stage and region was calculated as a simple average over all years. To standardize these data, the average observed density for each life stage and region was then divided by the highest average annual observed density for that life stage and multiplied by 100.

While recognizing that the gear employed to sample Estuary fishes varies in catch efficiency, and that catch efficiency varies both between monitoring programs and within samples of each monitoring program depending on a variety of factors including the size of individual fish, we did not attempt to adjust the results reported here for catch efficiency. As a result, we did not attempt to draw conclusions regarding differences in densities between monitoring programs, or between life stages within a given monitoring program.

Our treatment of catch data was limited to frequency of observation and average observed density, rather than population estimates. The latter would have required estimates of the volume of the body of water and reliance on the assumption that samples are representative of the density of smelt in the targeted water body. The validity of such an assumption may be questionable in a variety of circumstances, particularly when using Beach Seine data since the demarcation between "beach habitat" and "open-water habitat" is difficult to specify.

To describe the temporal extent of the presence of each life stage across all years, we calculated the frequency of observation and observed density by month for each life stage. In so doing, we built upon the conceptual and analytical work of Bennett (2005), who provided a model of delta smelt life history that included the approximate months during which each life stage exists. The percentage of delta smelt caught in any individual month was calculated as the total number of smelt of that life stage caught in that month since 1995, divided by the total number of smelt of that life stage caught since 1995. Because we did not attempt to compare catch between monitoring programs, we reported this result separately for each monitoring program. We also reported the frequency with which each life stage was observed in each month in each monitoring program.

Results

Within the 21 identified regions of the San Francisco Estuary, we identified 289,401 survey events (a sampling event at a given location and time) at 624 monitoring stations. Of these, 444 (71%) were from IEP and 180 (29%) were from regional monitoring programs. The program with the single greatest number of monitoring stations was FMWT (136), followed by the Beach Seine (97), 20-mm (67), Kodiak (53), BMWT (52), and STN (39) (Table 1). Delta smelt were observed at 347 of the 444 (78%) IEP monitoring stations and at 83 of the 180 (46%) regional monitoring stations identified in this study.

Observed geographic extent.—Delta smelt were observed in all of the 21 regions covering an area of about 51,800 ha (Figure 2). Observations occurred as far west as Berkeley in San Francisco Bay, north on the Sacramento River to its confluence with the Feather River, and the San Joaquin River south of Stockton. Tributary observations included the Napa River, Cache Slough, the American River to the north, and the Mokelumne and

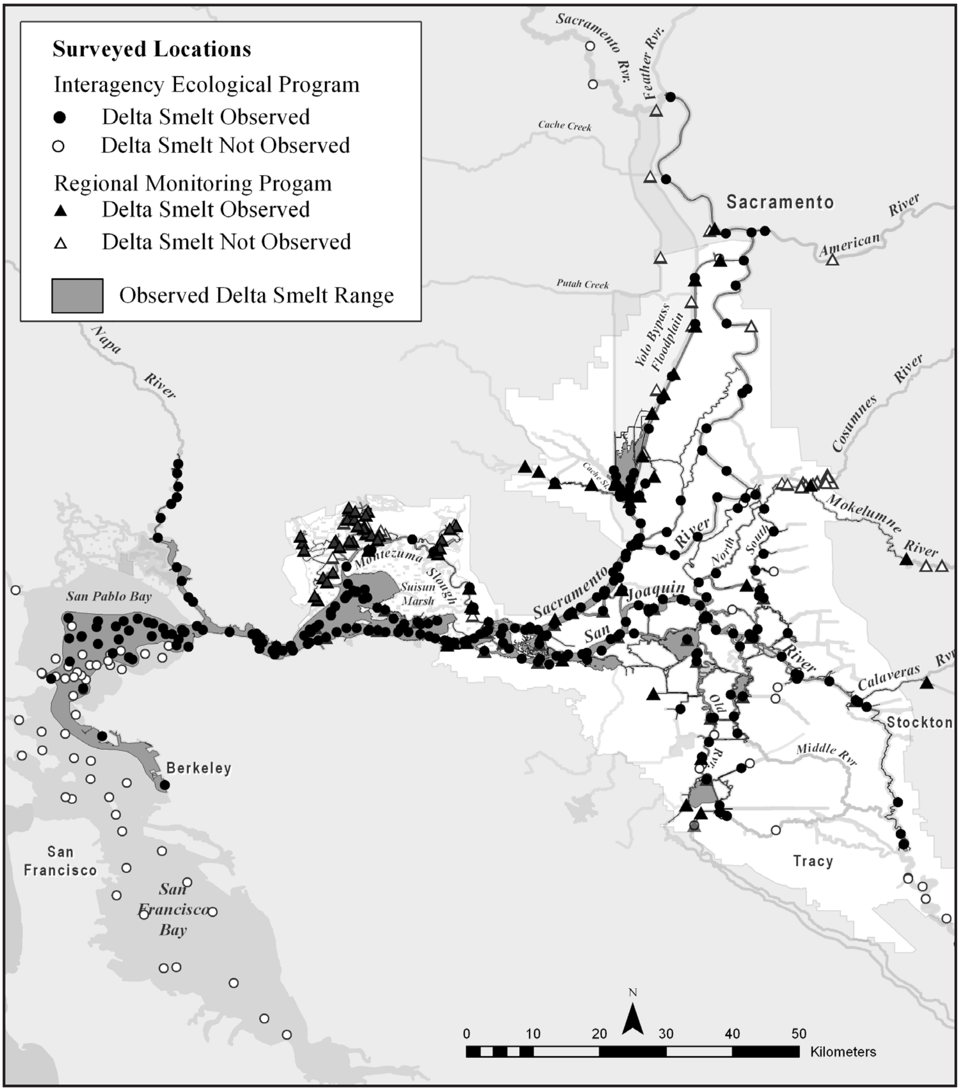

FIGURE 2.—Observations of delta smelt at monitoring stations of Interagency Ecological Program and Regional surveys. Circles indicate Interagency Ecological Program stations where delta smelt were observed (closed) or not observed (open). Triangles indicate Regional survey stations where delta smelt were observed (closed) or not observed (open). The outlined area represents the observed delta smelt range.

Calaveras rivers to the east. Delta smelt were also observed in seasonally-inundated habitat of the Yolo Bypass and the Cosumnes River at its confluence with the Mokelumne River.

No single IEP monitoring program sampled all of the 21 regions (Table 1) that make up the observed extent of range (Figures 3 to 5). The 20-mm and the FMWT had the highest coverage (80% of regions each). The STN covered 71% of the regions, while coverage among the other IEP surveys ranged from 57 to 76%.

Distribution by life stage.—Delta smelt larvae were observed in the Estuary from March through July, sub-juveniles during April through August, juveniles during May

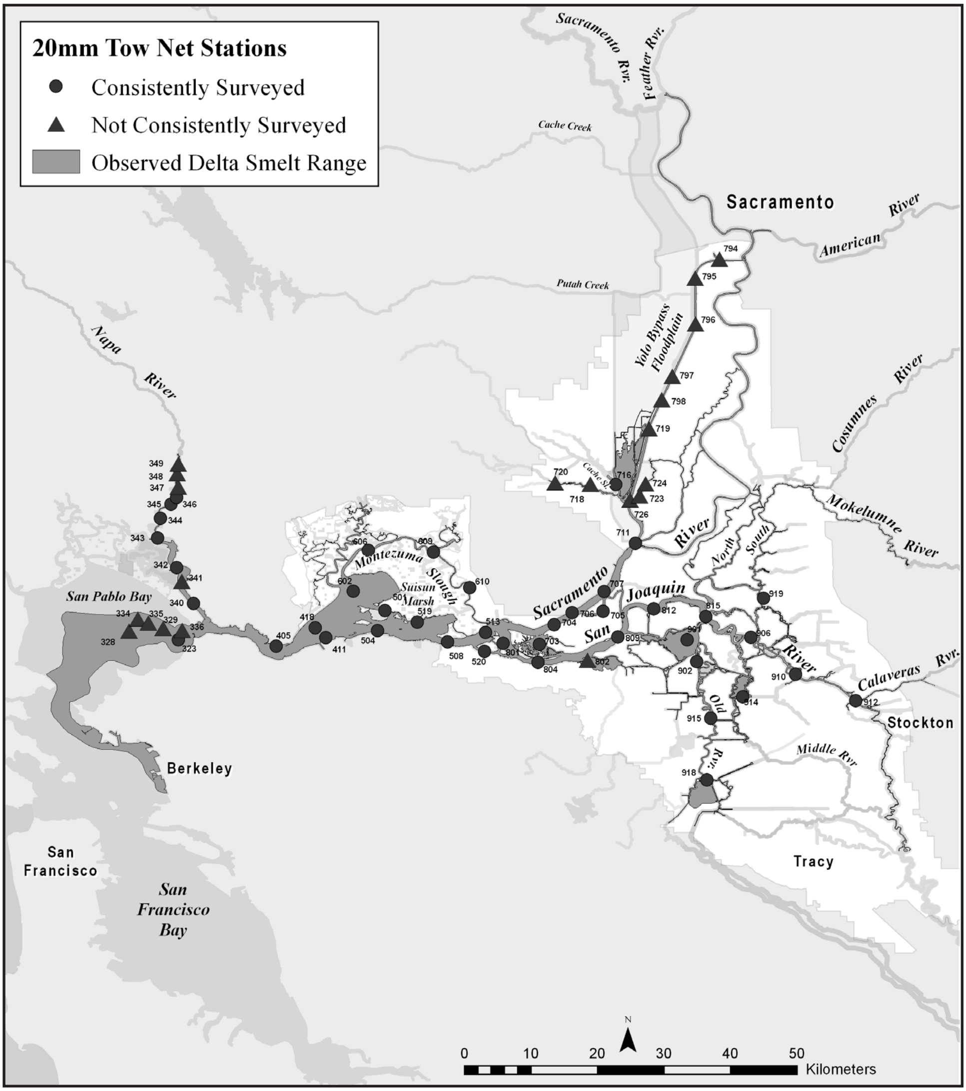

Figure 3.—Location of 20-mm Tow-Net survey stations in relation to the observed delta smelt range (outlined area). Circles represent stations consistently surveyed across all years (1995-2009). Triangles represent stations not consistently surveyed.

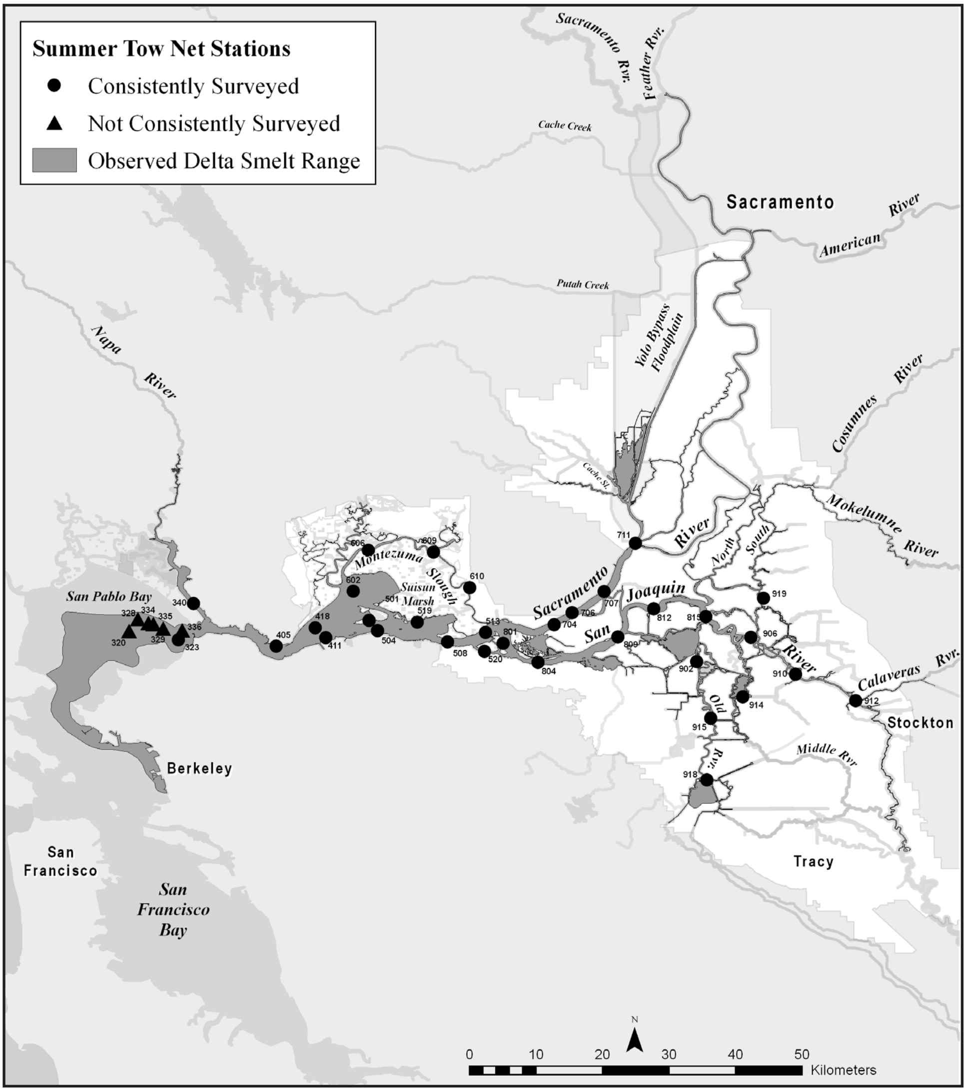

Figure 4.—Location of Summer Tow Net survey stations in relation to the observed delta smelt range (outlined area). Circles represent stations consistently surveyed across all years (1995-2009). Triangles represent stations not consistently surveyed.

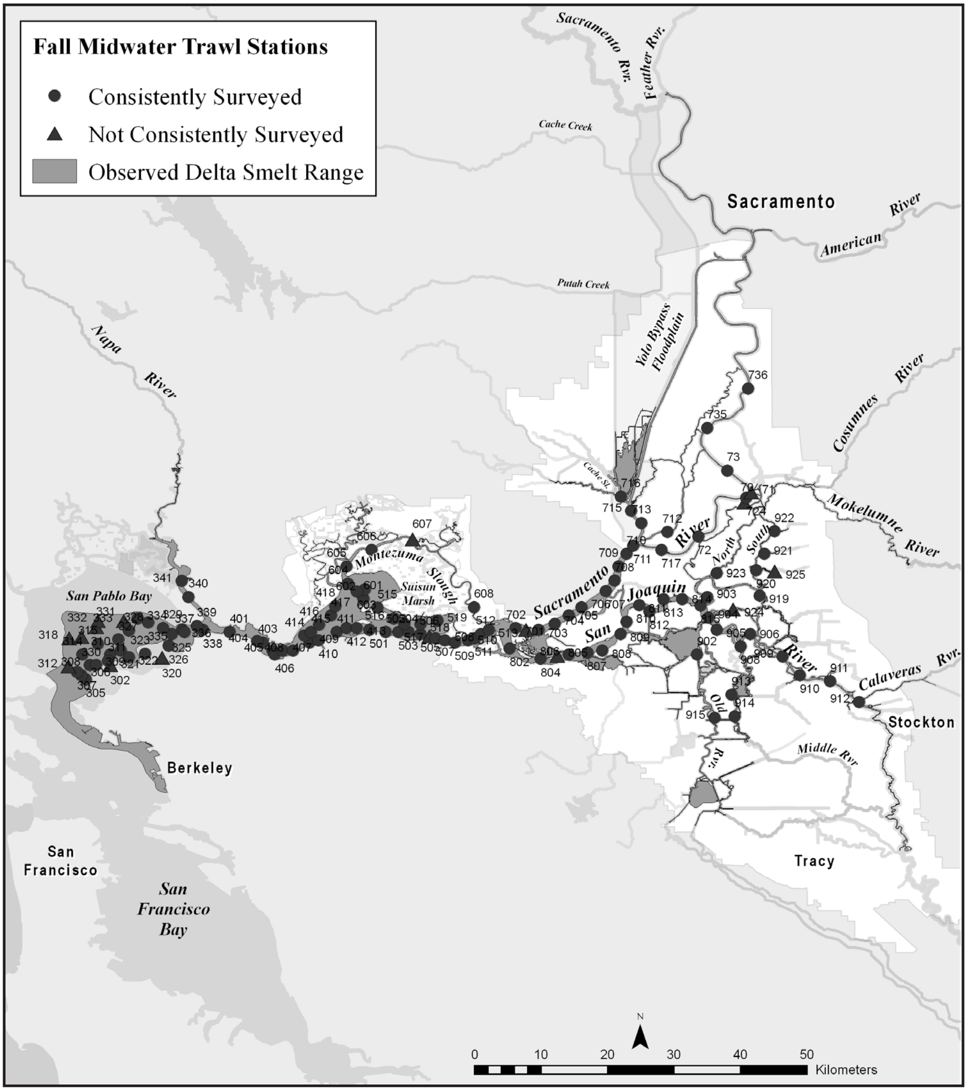

Figure 5.—Location of Fall Mid-Water Trawl survey stations in relation to the observed delta smelt range (outlined area). Circles represent stations consistently surveyed across all years (1995-2009). Triangles represent stations not consistently surveyed.

through December, sub-adults during September through December, and pre-spawning and spawning adults during January through May (Tables 5 and 6). For most life stages, delta smelt were observed most frequently near the center of their range — from Suisun Marsh down through Grizzly Bay and east Suisun Bay through the Confluence to the Lower

Table 5.—Percent of years delta smelt were observed in each month in at least one location in the Estuary by life stage and monitoring program (1995-2009). 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net, FMWT = Fall Midwater Trawl, BS = Beach Seine, BMWT = Bay Midwater Trawl, and SKT = Spring Kodiak Trawl.

Life Stage	Monitoring Program	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Larvae	20-mm			64%	100%	100%	100%	43%	0%				
Sub-juvenile	20-mm			0%	93%	100%	100%	93%	50%				
Sub-juvenile	STN						100%	93%	58%				
Juvenile	20-mm			0%	7%	93%	100%	93%	50%				
Juvenile	STN						100%	100%	100%				
Juvenile	FMWT									87%	80%	73%	53%
Sub-adults	FMWT									100%	93%	93%	100%
Mature Adults	BS	69%	81%	94%	94%	93%						38%	56%
Mature Adults	BMWT	89%	80%	89%	92%	75%	58%	75%	100%	75%	8%	0%	18%
Pre-spawning	SKT	100%	100%	100%	100%	100%							
Spawning	SKT	43%	75%	100%	100%	50%							

Table 6.—Percent of total delta smelt catch occurring in each month by lifestage and monitoring program (1995-2009). 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net, FMWT = Fall Midwater Trawl, BS = Beach Seine, BMWT = Bay Midwater Trawl, and SKT = Spring Kodiak Trawl.

Life Stage	Monitoring Program	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Larvae	20-mm	1995-2009			2%	59%	29%	9%	1%					
Sub-juvenile	20-mm	1995-2009			0.0%	5%	43%	43%	9%	0.3%				
Sub-juvenile	STN	1995-2009						34%	56%	11%				
Juvenile	20-mm	1995-2009			0.0%	0.0%	5%	55%	38%	3%				
Juvenile	STN	1995-2009						18%	56%	26%				
Juvenile	FMWT	1995-2009									40%	37%	14%	9%
Sub-adults	FMWT	1995-2009									16%	34%	28%	22%
Mature Adults	BS	1995-2009	9%	10%	31%	21%	17%						2%	10%
Mature Adults	BMWT	1995-2006	20%	12%	17%	23%	7%	3%	9%	5%	3%	0.2%	0.0%	
Pre-spawning	SKT	2002-2009	45%	34%	16%	4%	1%							
Spawning	SKT	2002-2009	4%	23%	53%	17%	4%							

Sacramento River region, but also in the region of Cache Slough (Figure 6). Regions where delta smelt were observed most frequently (regions in the upper quartile of each column in Table 7) for any life stage were northeast Suisun Bay, Grizzly Bay, Suisun Marsh, Confluence, Lower Sacramento River, Upper Sacramento River, Cache Slough and Ship Channel, and

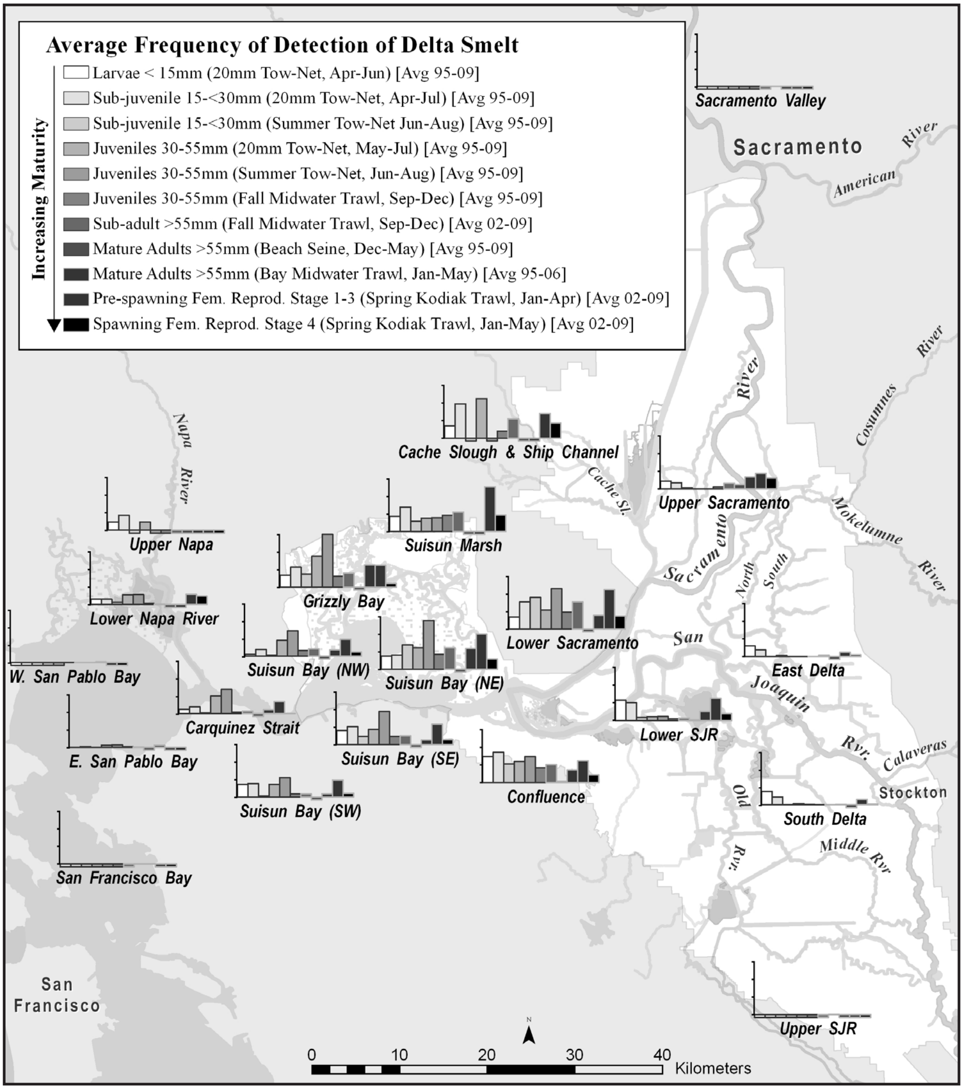

FIGURE 6.—Average annual frequency of delta smelt observation (percentage of sampling events where delta smelt were observed) by life stage and Region for Interagency Ecological Program surveys. Regions where the average frequency of detection for a given life stage was zero are indicated by no data column being present. Regions that were not sampled for a given life stage are indicated by a data column suspended slightly below the x-axis. Y-axis ticks indicate frequencies of 0, 25, 50, 75, and 100 percent.

Table 7.—Average annual frequency of delta smelt occurrence by life stage, IEP monitoring program, and region. 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net, FMWT = Fall Midwater Trawl, BS = Beach Seine, BMWT = Bay Midwater Trawl, and SKT = Spring Kodiak Trawl. NS indicates no survey conducted in the given life-stage and region.

	Life-stage										
	Larvae	Sub-juvenile		Juvenile			Sub-adult	Mature Adults		Pre-spawning	Spawning
Monitoring Program	20-mm	20-mm	STN	20-mm	STN	FMWT	FMWT	Beach Seine	BMWT	Kodiak Trawl	Kodiak Trawl
Years of data used	95-09	95-09	95-09	95-09	95-09	95-09	95-09	95-09	95-06	02-09	02-09
Time period	Apr-Jun	Apr-Jul	Jun-Aug	May-Jul	Jun-Aug	Sep-Dec	Sep-Dec	Dec-May	Jan-May	Jan-Apr	Jan-May
San Francisco Bay	NS	NS	NS	NS	NS	NS	NS	0.0%	0.0%	NS	NS
West San Pablo Bay	NS	NS	NS	NS	NS	0.2%	0.0%	0.0%	1.2%	NS	NS
East San Pablo Bay	0.0%	1.0%	0.0%	2.8%	3.6%	0.7%	0.6%	NS	2.7%	NS	NS
Lower Napa River	7.3%	7.7%	3.3%	13.3%	14.0%	1.7%	0.8%	NS	NS	14.3%	11.8%
Upper Napa River	11.6%	21.2%	NS	12.0%	NS	NS	NS	NS	NS	NS	NS
Carquinez Strait	5.7%	9.3%	1.1%	24.4%	33.7%	1.9%	3.3%	NS	5.4%	16.7%	0.0%
Suisun Bay (SW)	17.8%	18.3%	1.3%	17.5%	26.9%	4.3%	4.3%	NS	4.3%	23.3%	5.6%
Suisun Bay (NW)	2.2%	8.9%	1.1%	21.7%	34.8%	7.3%	10.0%	NS	8.7%	23.3%	5.6%
Suisun Bay (SE)	19.5%	24.9%	11.0%	20.9%	45.7%	11.0%	12.1%	NS	6.5%	28.3%	6.9%
Suisun Bay (NE)	17.8%	19.2%	33.6%	29.7%	66.7%	20.3%	29.3%	NS	28.3%	48.3%	13.9%
Grizzly Bay	16.3%	27.6%	17.9%	42.9%	72.8%	15.0%	19.6%	NS	30.4%	30.0%	5.6%
Suisun Marsh	21.4%	33.6%	14.2%	18.5%	19.2%	22.8%	27.2%	NS	NS	62.0%	23.1%
Confluence	35.7%	41.6%	25.7%	29.2%	36.1%	20.2%	24.5%	1.8%	17.4%	30.0%	10.4%
Lower Sacramento River	16.5%	37.0%	43.3%	26.2%	55.5%	22.9%	37.1%	NS	18.8%	54.4%	17.8%
Upper Sacramento River	10.8%	8.2%	1.3%	0.0%	0.0%	2.7%	8.0%	5.8%	16.7%	21.7%	15.3%
Cache Slough & Ship Channel	17.2%	47.3%	NS	54.3%	NS	9.8%	26.7%	NS	NS	33.9%	21.1%
Lower San Joaquin River	28.0%	24.5%	4.1%	5.1%	5.6%	2.6%	3.5%	0.9%	12.6%	30.6%	9.7%
East Delta	14.6%	8.8%	0.0%	1.2%	0.0%	0.0%	0.0%	1.6%	NS	5.7%	2.3%
South Delta	18.4%	10.8%	0.0%	1.4%	0.3%	0.0%	0.0%	0.3%	NS	7.1%	1.1%
Upper San Joaquin River	NS	NS	NS	NS	NS	NS	NS	0.2%	NS	NS	NS
Sacramento Valley	NS	NS	NS	NS	NS	NS	NS	0.2%	NS	NS	NS

Lower San Joaquin River. Westward of Suisun Bay, the frequency of observation tended to decrease as the distance from Suisun Bay increased. San Pablo Bay typically had the lowest observed frequencies west of Suisun Bay. The East and South Delta regions generally had low observed frequencies relative to other regions for the same life stage. The exception was for larval delta smelt where these regions (with observed frequencies of 15% and 18%, respectively) were close to the median observed frequency of 16%.

Delta smelt were observed at higher densities near the center of their range — the same area where they were observed most frequently: from Suisun Marsh down through Grizzly Bay and east Suisun Bay through the Confluence to the Lower Sacramento River region, but also in the Cache Slough region (Figure 7). The regions where delta smelt were

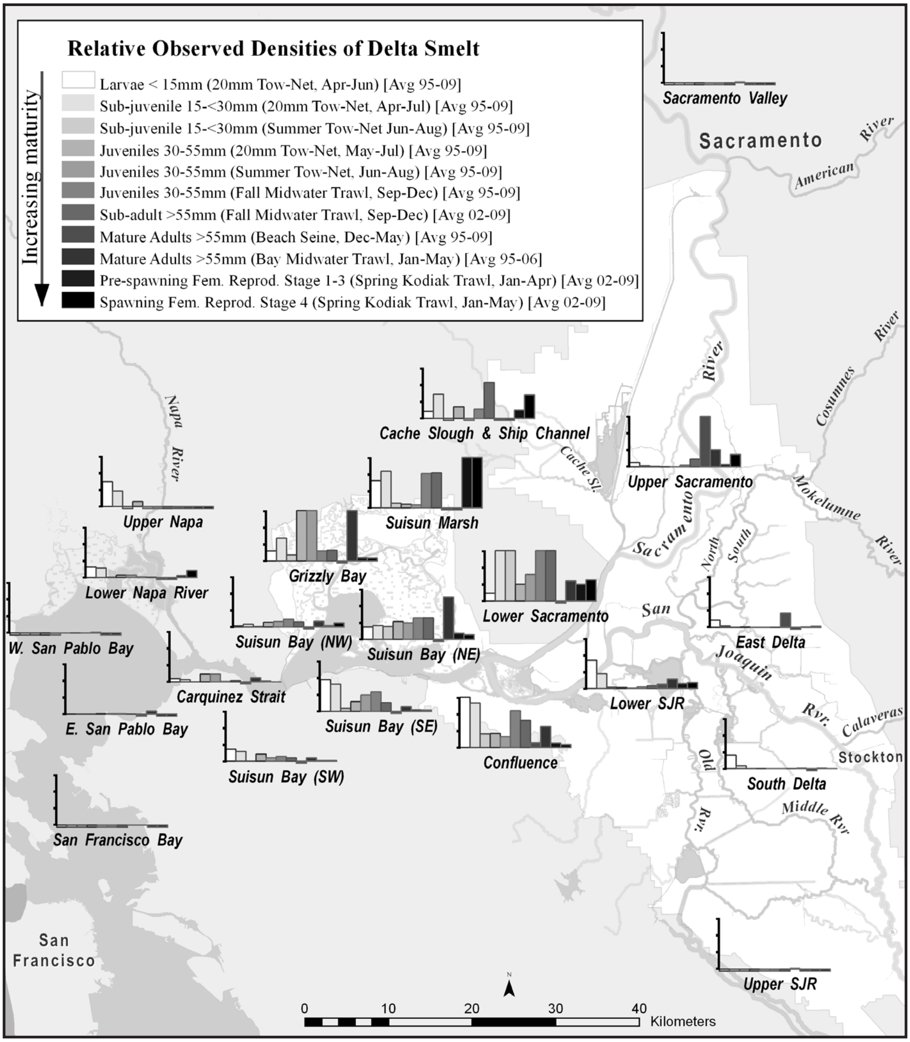

FIGURE 7.—Relative observed densities (average density for each life stage and region divided by highest average annual density observed for that life stage multiplied by 100) of delta smelt by life stage and region for Estuary-wide surveys. Regions where the relative observed density for a given life stage was zero are indicated by no data column being present. Regions that were not sampled for a given life stage are indicated by a data column suspended slightly below the x-axis. Y-axis ticks indicate 0, 25, 50, 75, and 100 percent of highest observed density.

observed in the greatest densities were the Confluence for larvae in the 20-mm; Lower Sacramento River for sub-juveniles in both the 20-mm and STN; Grizzly Bay for juveniles in the 20-mm and STN, but Lower Sacramento River for juveniles later in the year in the FMWT; Lower Sacramento River for sub-adults in the FMWT; Upper Sacramento River for mature adults in the Beach Seine; Grizzly Bay for mature adults in the BMWT; and Suisun Marsh for both pre-spawning and spawning adults in the Kodiak (Table 8). Regions with the highest average observed densities (regions in the upper quartile of each column in Table 8) for any life stage were northeast Suisun Bay, Grizzly Bay, Suisun Marsh, Confluence, Lower Sacramento River, and Upper Sacramento River. Delta smelt observed densities (for all but the earliest life stages) were low in the western Suisun Bay and regions further to the west, and in the east and south Delta, relative to other areas.

Discussion

Observed geographic extent.—Extent of habitat is a critical piece of information for assessing the conservation status of a species (e.g., Millsap et al. 1990, IUCN 1994, Lunney et al. 1996, Burgman and Fox 2003). The historical range of delta smelt was provided by Sweetnam and Stevens (1993) who described the species as existing as far upstream in the Sacramento River as the Feather River mouth (citing Wang 1991) and Mossdale on the San Joaquin River (citing Moyle et al. 1992), and downstream to western Suisun Bay.

We utilized recently available data from the 20-mm (since 1995) and Kodiak (since 2002), together with other IEP and regional monitoring programs (since 1995) to provide information on areas of the Estuary where identified delta smelt life stages have been observed. Though our study included additional portions of San Pablo Bay not detailed by Sweetnam and Stevens (1993), we identified essentially the same distribution of delta smelt on the Napa River, Cache Slough, Suisun Marsh tributaries, and San Joaquin River inferred by the earlier study.

Observations at the most upstream sampling stations in the Napa River, Cache Slough, and Sacramento and Calaveras rivers indicate that the extent of delta smelt distribution in these locations remains unknown. Recently, Cache Slough and its tributaries have been identified as key habitat for delta smelt across all life stages (DSC 2010). However, available survey data suggest the full distributional range of delta smelt in the Cache Slough drainage has not been identified by current sampling efforts. These observations suggest sampling locations beyond those covered by current IEP monitoring could yield further insights into distribution and habitat requirements of this endangered fish.

Distribution by life stage.—While numerous factors affect the distribution of delta smelt (EET 1997, Meng and Matern 2001, Bennett et al. 2002, Kimmerer 2002, Baskerville-Bridges et al. 2004, Dege and Brown 2004, Feyrer 2004, Grimaldo et al. 2004, Sommer et al. 2004, Bennett 2005, Feyrer et al. 2007, Baxter et al. 2008, Nobriga 2008), it was beyond the scope of this paper to relate distribution to causal factors. Nevertheless, important information can be gleaned from this review, which may inform conservation planning and lead to research into factors driving delta smelt distribution. For example, high frequency of observation and observed density of mature adults and early life stages are indicators of areas that could be spawning regions (Sommer et al. 2011). Spawning occurring upstream in freshwater has been supported elsewhere through high catches of larval delta smelt along the edges of rivers and in adjoining sloughs in the western Delta (Moyle et al. 1992). The newer IEP monitoring programs provide potentially important information regarding general spawning locations. The relatively higher presence of spawning adults in Suisun Marsh, Cache Slough, and the Lower Sacramento River indicate possible proximity to spawning areas, a suggestion also supported by high relative observed densities of larval smelt in downstream areas. The Upper Napa River has relatively high observed densities of larvae, suggesting that this may also be an important area for spawning; considering their poor swimming ability, it is unlikely that larvae would have migrated up the Napa River from other locations. The Napa River, which at one time was considered to be a population sink for delta smelt, is now considered a contributor to the adult population (Hobbs et al. 2007).

An important rearing area appears to be the stretch of water between the Lower Sacramento River and Grizzly Bay, with Grizzly Bay supporting an increasing proportion of young delta smelt as they mature. The highest relative observed densities of juveniles in STN (with surveys from June to August) were found in Grizzly Bay. This is corroborated by data from the 20-mm, which also showed Grizzly Bay to have the highest relative observed densities of juveniles (May to July). By fall, the FMWT data indicate the highest relative observed juvenile densities usually are found further to the east in the Confluence and Lower Sacramento River regions — an area where sub-adults were also found in relatively high observed densities.

Spawning in the upstream regions of Napa River, Suisun Marsh, the Upper Sacramento River and Cache Slough, and maturing downstream in waters from Grizzly Bay upstream to the Lower Sacramento River is consistent with the well-noted migration of delta smelt (Grimaldo et al. 2009, Sommer et al. 2011). The data also suggest year-round populations in the central regions (Lower Sacramento River downstream to Suisun Marsh) and in the Cache Slough and Ship Channel region. Collectively, these observations, along with the report of Hobbs et al. (2007), are an indication of variability in the migratory patterns observed by Sommer et al. (2011).

Outside of the central regions, the Cache Slough and Ship Channel was the only region that yielded high catches of delta smelt relative to other regions across multiple life stages for years 1995-2009. Recent monitoring efforts have shown that delta smelt are utilizing the near-shore habitats of the Cache Slough and Ship Channel region (a restored tidal marsh) not only during the spawning season, but also on a year-round basis (DSC 2010). Many IEP studies are underway to understand the environmental mechanisms in Cache Slough that help create critical habitat for delta smelt.

A number of observations can be taken from these distributional data that could contribute to more effective conservation planning for delta smelt. First, some of the highest observed densities of delta smelt are found close to shore (Table 8), suggesting that some necessary or desired habitat conditions exist along the shoreline, possibly related to migration (Sommer et al. 2011) or spawning. Second, it could be inferred from subregional delta smelt observed densities that, under contemporary conditions, the fish seem to be exhibiting higher densities in areas that are most similar to historic habitat — deep channels that occur proximate to more extensive areas of shallow water (Whipple 2010), which may to some degree be insulated from the influences of anthropogenic environmental stressors. Third, it appears that the monitoring programs may be missing useful information at some life stages in areas potentially important for delta smelt (e.g., areas upstream of existing consistently monitored stations in the Napa River, around Cache Slough and the adjacent ship channel, and several other tributaries to the Sacramento River).

Table 8.—Average observed densities (number of fish per 10,000 m3) of delta smelt by life stage, Interagency Ecological Program monitoring program, and region. 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net, FMWT = Fall Midwater Trawl, BS = Beach Seine, BMWT = Bay Midwater Trawl, and SKT = Spring Kodiak Trawl. NS indicates no survey conducted in the given life-stage and region.

	Life-stage										
	Larvae	Sub-juvenile		Juvenile			Sub-adult	Mature Adults		Pre-spawning	Spawning
Monitoring Program	20-mm	20-mm	STN	20-mm	STN	FMWT	FMWT	Beach Seine	BMWT	SKT	SKT
Years of Data Used	95-09	95-09	95-09	95-09	95-09	95-09	95-09	95-09	95-06	02-09	02-09
Time Period	Apr-Jun	Apr-Jul	Jun-Aug	May-Jul	Jun-Aug	Sep-Dec	Sep-Dec	Dec-May	Jan-May	Jan-Apr	Jan-May
San Francisco Bay	NS	NS	NS	NS	NS	NS	NS	0.0	0.0	NS	NS
West San Pablo Bay	NS	NS	NS	NS	NS	0.0	0.0	0.0	0.0	NS	NS
East San Pablo Bay	0.0	0.0	0.0	0.1	0.4	0.0	0.0	NS	0.1	NS	NS
Lower Napa River	2.0	3.6	0.2	1.2	3.3	0.1	0.0	NS	NS	1.1	0.4
Upper Napa River	4.6	6.0	NS	2.5	NS	NS	NS	NS	NS	NS	NS
Carquinez Strait	0.5	0.8	0.0	3.9	10.2	0.0	0.1	NS	0.1	0.4	0.0
Suisun Bay (SW)	2.3	3.7	0.1	3.4	4.6	0.4	0.3	NS	0.1	0.3	0.0
Suisun Bay (NW)	0.1	0.9	0.1	2.3	6.8	0.6	0.4	NS	0.1	0.6	0.2
Suisun Bay (SE)	5.9	10.4	0.9	4.8	22.1	1.6	0.7	NS	0.1	0.9	0.1
Suisun Bay (NE)	2.3	5.2	3.7	8.7	21.6	1.8	1.8	NS	1.0	3.0	0.3
Grizzly Bay	1.9	8.7	1.8	24.8	67.1	0.8	0.9	NS	1.2	1.6	0.2
Suisun Marsh	5.0	13.9	1.3	1.7	3.7	2.8	2.9	NS	NS	24.8	3.1
Confluence	9.4	17.0	3.9	7.0	14.8	3.1	2.3	3.9	0.5	2.2	0.2
Lower Sacramento River	1.4	19.3	14.7	8.3	35.1	4.2	4.2	NS	0.5	8.2	1.3
Upper Sacramento River	0.8	0.4	0.1	0.0	0.0	0.1	0.7	39.3	0.4	1.1	0.8
Cache Slough & Ship Channel	1.3	9.2	NS	5.7	NS	0.8	3.0	NS	NS	4.1	1.5
Lower San Joaquin River	5.2	5.6	0.4	0.4	0.4	0.1	0.2	3.4	0.2	2.4	0.4
East Delta	1.3	0.5	0.0	0.1	0.0	0.0	0.0	10.9	NS	0.1	0.0
South Delta	2.5	1.0	0.0	0.1	0.0	0.0	0.0	0.4	NS	0.2	0.0
Upper San Joaquin River	NS	NS	NS	NS	NS	NS	NS	0.4	NS	NS	NS
Sacramento Valley	NS	NS	NS	NS	NS	NS	NS	0.6	NS	NS	NS

According to Feyrer et al. (2007), one factor limiting the utility of delta smelt empirical data is that those data frequently pertain to a particular life stage or time period when sampling was conducted. Thompson et al. (2010) suggested a life history model linking the abundances of each life stage would provide a more continuous picture of the population and would capitalize more fully on available data. Martin et al. (2007) suggested that conservation of migratory species depends largely on understanding links between different periods of life cycles. These suggestions highlight the importance of, and the need for, a clearer understanding of the distribution of the various life stages of delta smelt.

Concepts regarding restoration of native fish habitat and buffering from potential environmental disaster within the San Francisco Estuary have evolved considerably in recent years, particularly the restoration of tidal wetlands and floodplain habitats (Moyle 2008). While significant issues include the management of flow, invasive species responses, and future climatic effects (Brown and May 2006), our review provides important information on the life stage-specific distribution of delta smelt that was made possible by monitoring programs implemented by the IEP and other agencies since 1995.

According to Holl et al. (2003), a common conclusion of many restoration efforts is that success varies substantially among sites. At least in part, varying success results from differences in hydrology, microclimate, and movement of plants, animals, and disturbance regimes. Our review of the spatial distribution of delta smelt highlights general regions that appear important for specific life stages. Such information will be useful when addressing management issues such as anthropogenic stressors, habitat restoration efforts, and testing the success of experimental approaches to achieving habitat objectives for desirable species (Moyle et al. 2010). This comprehensive review of delta smelt distribution within the San Francisco Estuary provides managers and scientists an improved depiction of the spatial and temporal extent of the delta smelt throughout its range, and lends itself to future analysis of population assessment and restoration planning.

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Abstract:

Differing and confounding understandings of the seasonal movements of the delta smelt (*Hypomesus transpacificus*) in the San Francisco Estuary persist nearly 2 decades after its listing as threatened under the federal and state endangered species acts. The U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation have characterized the delta smelt as a species that migrates extensive distances from Suisun Bay and the Sacramento and San Joaquin rivers confluence in the fall and winter, eastward and upstream to the central and east Sacramento–San Joaquin Delta to spawn, with the next generation returning to downstream rearing areas in the following spring (OCAP Technical Support Team unpublished; USBR 2012). This description of inter-seasonal movements of delta smelt stands in contrast to findings drawn from previous studies, which describe movements by pre-spawner delta smelt from open waters in bays and channels to proximate marshlands and freshwater inlets (e.g., Moyle et al. 1992; Bennett 2005). In an effort to resolve this disagreement over the movements of delta smelt, we use publicly available data on its distribution drawn from trawl surveys to generate maps from which we infer seasonal patterns of dispersal. In the fall, before spawning, delta smelt are most abundant in Suisun Bay, the Sacramento and San Joaquin rivers confluence, the lower Sacramento River, and the Cache Slough complex. By March and April, the period of peak detection of spawning adults, relative densities in Suisun Bay and the rivers' confluence have diminished in favor of higher concentrations of delta smelt in Montezuma Slough and the Cache Slough complex. A relatively small percentage of fish are observed in areas of the Sacramento River above Cache Slough. We conclude that inter-seasonal dispersal of delta smelt is more circumscribed than has been previously reported. This conclusion has real-world implications for efforts to conserve delta smelt. Our findings support a conservation strategy for delta smelt that focuses on habitat restoration and management efforts for tidal marsh and other wetlands in north Delta shoreline areas directly adjacent to open waters that have been documented to support higher concentrations of the fish.

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Eastward Migration or Marshward Dispersal: Understanding Seasonal Movements by Delta Smelt

Dennis D. Murphy[1] and Scott A. Hamilton[2]

ABSTRACT

Differing and confounding understandings of the seasonal movements of the delta smelt (*Hypomesus transpacificus*) in the San Francisco Estuary persist nearly 2 decades after its listing as threatened under the federal and state endangered species acts. The U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation have characterized the delta smelt as a species that migrates extensive distances from Suisun Bay and the Sacramento and San Joaquin rivers confluence in the fall and winter, eastward and upstream to the central and east Sacramento–San Joaquin Delta to spawn, with the next generation returning to downstream rearing areas in the following spring (OCAP Technical Support Team unpublished; USBR 2012). This description of inter-seasonal movements of delta smelt stands in contrast to findings drawn from previous studies, which describe movements by pre-spawner delta smelt from open waters in bays and channels to proximate marshlands and freshwater inlets (e.g., Moyle et al. 1992; Bennett 2005). In an effort to resolve this disagreement over the movements of delta smelt, we use publicly available data on its distribution drawn from trawl surveys to generate maps from which we infer seasonal patterns of dispersal. In the fall, before spawning, delta smelt are most abundant in Suisun Bay, the Sacramento and San Joaquin rivers confluence, the lower Sacramento River, and the Cache Slough complex. By March and April, the period of peak detection of spawning adults, relative densities in Suisun Bay and the rivers' confluence have diminished in favor of higher concentrations of delta smelt in Montezuma Slough and the Cache Slough complex. A relatively small percentage of fish are observed in areas of the Sacramento River above Cache Slough. We conclude that inter-seasonal dispersal of delta smelt is more circumscribed than has been previously reported. This conclusion has real-world implications for efforts to conserve delta smelt. Our findings support a conservation strategy for delta smelt that focuses on habitat restoration and management efforts for tidal marsh and other wetlands in north Delta shoreline areas directly adjacent to open waters that have been documented to support higher concentrations of the fish.

KEY WORDS

delta smelt, *Hypomesus transpacificus*, distribution, dispersal, spawning migration, inter-seasonal movement

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INTRODUCTION

From assessments of gene flow to projections of metapopulation dynamics, virtually every essential aspect of conservation planning calls for an understanding of patterns of movement by targeted at-risk species. And, while a rough appreciation of dispersal exists for most protected species, the once-abundant delta smelt (*Hypomesus transpacificus*), which is endemic to central California's San Francisco Estuary (estuary), is a species for which an absence of data on dispersal has fed controversy over appropriate conservation actions needed to recover and restore its habitats, and over the allocation of resources required to protect it. Because the fish is small, nearly transparent, and preternaturally fragile, the movements of delta smelt have proven exceptionally difficult to track in the turbid waters of the estuary. So elusive is the fish throughout its annual life cycle, it actually has not been observed spawning in nature (Moyle 2002; Bennett 2005); and, while its distributional range has recently been resolved to the extent practicable using available surveys (Merz et al. 2011), its dispersal patterns within that range remain in doubt (but see Bennett 2005). Data from a series of trawl surveys in the estuary suggest that different delta smelt life stages use different areas of the estuary's water bodies and channels. However, since with few exceptions, delta smelt are not directly observed in those habitats and cannot readily be marked or tagged, many uncertainties remain about the details of delta smelt movements (Sommer et al. 2011).

Individual survey samples that capture delta smelt offer limited direct information regarding dispersal by the species. Sequential analysis of data from multiple trawl-based surveys parsed by life-stage can provide evidence of continuously shifting populations. Although the movements of individual delta smelt remain obscure, geographic patterns of its presence and absence, and its temporally and spatially shifting densities, can be gleaned from the sequential trawl surveys and used to infer inter-seasonal patterns in its movements.

Based on publicly available long-term data sets on the distribution of the species, two dramatically differing perspectives have emerged in the literature and in federal agency planning documents and presentations on adult delta smelt movement before spawning. One perspective is provided by Bennett (2005), who noted that in "the fall, delta smelt gradually begin a diffuse migration landward to the freshwater portion of the Delta, and during wetter years to the channels and sloughs in Suisun Marsh and the lower Napa River." Bennett's description is consistent with that articulated by Moyle (2002 and Moyle et al. 1992), reflecting previous observations from focused surveys reported by Radtke (1966), Wang (1986, 1991), and Wang and Brown (1993). These studies depict dispersal in multiple directions by pre-spawner delta smelt, from the bays, embayments, and channels of the estuary's low-salinity zone, to adjacent marshlands and freshwater inlets that support spawning. Juvenile fish that emerge to become the next generation distribute themselves into adjacent open waters where they feed and grow for several months, followed by a repeat of the cycle of dispersal toward marshland and freshwater spawning locations.

The other perspective on delta smelt movement is described by Sommer et al. (2011) as a uniform, upstream migration from open waters in western portions of the Delta's low-salinity zone toward its eastern freshwater limits. Department of the Interior agencies illustrate the premise of large-scale, seasonal, directional movement by delta smelt in a pair of maps. Figure 1A illustrates a seasonally bimodal distribution of delta smelt in which the fish feeds and matures in the western Delta and Suisun Bay from the early spring to the late autumn and early winter, at which time pre-spawning adults undergo a unidirectional migration to a distinct eastern distribution for spawning (OCAP Technical Support Team unpublished). The next generation returns to previously occupied west estuary waters to repeat the cycle. The second map (Figure 1B) shows an eastward shift in the distribution of delta smelt, but from a broader, mid-year footprint in the western portion of the Delta toward a partially overlapping, more-eastern distribution just before spawning, followed by a return to the more western distribution by the next generation (USBR 2012). The presentations that accompanied both maps described those seasonal shifts in distribu-

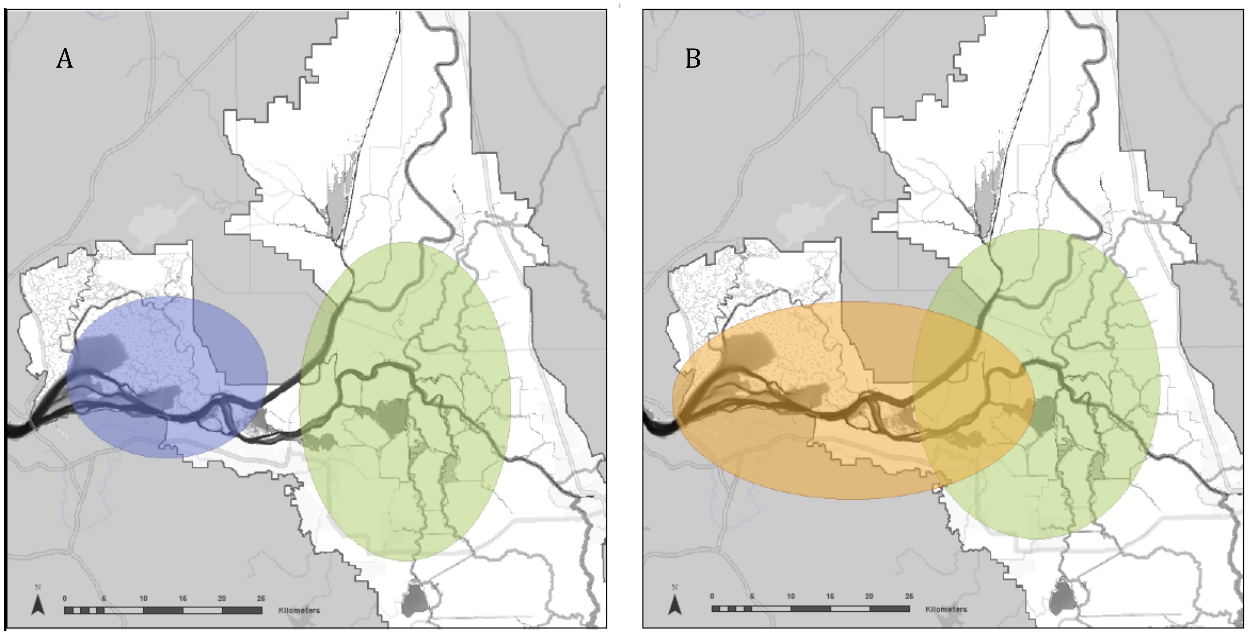

Figure 1 Conceptual mapped and inferred distributions of delta smelt seasonal dispersal in the San Francisco Estuary redrawn from a presentation by (**A**) the OCAP Technical Support team (unpublished) and (**B**) a guidance document from U.S. Bureau of Reclamation (2012). (**A**) portrays a migration of adult delta smelt from the Suisun Bay and the area of the Sacramento and San Joaquin rivers confluence (blue oval) to the central Sacramento–San Joaquin Delta in the winter and spring (green oval) before spawning. Offspring migrate back from the central Delta, returning to the western distributional footprint by summer. (**B**) depicts a shift of individuals eastward from a larger pre-spawning distribution from edge of Suisun Bay in the west to up into the lower Sacramento and San Joaquin rivers to the east (orange oval) to the central Delta (green oval) where spawning presumptively occurs.

tion as constituting migration events by spawning delta smelt.

Here we use state agency-generated survey data to produce maps of delta smelt distribution across seasons and to understand of where delta smelt are most commonly found during each of their several recognizable life stages. By comparing the locations of season- and life-stage-specific occurrence polygons, which include 95% of delta smelt sampled from five readily available fish surveys, we draw inferences concerning the fish's inter-seasonal movements. We contrast our findings with those presented in a recent assessment of the spawning migration of delta smelt in the upper estuary by Sommer et al. (2011).

We also consider the relevance of information on delta smelt distribution and dispersal to the multiple conservation planning efforts in the Delta. It appears that the first perspective has informed ongoing conservation planning efforts that target delta smelt, including recovery actions that directly target delta smelt, restoration efforts that seek to restore essential components of its diminished habitats, and management of flows through the Delta (USFWS 2008; USBR 2012; BDCP 2013). Implications of the two dispersal perspectives for the types, locations, and prioritization of species recovery actions and habitat restoration activities are profound. The more localized, marshward spawning dispersal phenomenon indicates the need for focused conservation actions in sub-regional context. In contrast, a long-distance migration phenomenon would expose delta smelt to distinct suites of environmental stressors during movement from one geographic limit of its west-to-east range to the other, and would invoke a different conservation agenda.

Here we address three assertions regarding the dispersal of delta smelt that are critical to the choice of a conceptual model. The assertions can be framed as hypotheses that, if not falsified with available data, would support the mass, upstream migration conceptual model for delta smelt:

1. Directional migration by delta smelt occurs in the late autumn and early winter from western and central portions of the estuary to areas in the eastern estuary.
2. In migrating seasonally to areas of the eastern Delta, delta smelt effectively vacate Suisun Bay and Suisun Marsh.
3. After spawning, sub-juvenile delta smelt are predominantly distributed across the central Delta.

We test these (*de facto*) hypotheses and draw inferences about the spatial distribution of delta smelt and likely patterns of its dispersal. We also consider how the loosely applied nomenclature of dispersal and the generous application of the term "migration" to the many manifestations of animal movement have combined to contribute to a confused narrative about the seasonal movements of delta smelt.

METHODS

Data Sources and Treatment

Since it is not possible at present to track delta smelt directly, inferences about its inter-seasonal movements require an assessment of the distribution of the fish at each of its life stages. The California Department of Fish and Wildlife carries out multiple surveys of fishes in the estuary, returns from which include delta smelt in temporal samples that span the fish's life cycle. Surveys include the 20-mm Survey, Summer Townet Survey (TNS), Fall Midwater Trawl Survey (FMWT), and Spring Kodiak Trawl Survey (SKT), which sample extensive, partially overlapping areas of the estuary (within the area in Figure 2). Additionally, USFWS conducts beach seine surveys in widely separated areas in the Delta. The methods for those surveys have been documented previously (see Moyle et al. 1992; Bennett 2005). Bennett (2005) has discussed in detail the varying strengths and weaknesses of several of those surveys as population assessment tools for delta smelt. Each monitoring program survey effort is conducted during a different seasonal (time) period, with a different sampling frequency (monthly or bi-weekly), and at a varying number of stations (30 to 113 stations). By employing different gear and tools during different time periods, each survey effort serves to sample delta smelt of different sizes and during different life stages. It is important to note that the first four of the ongoing surveys mentioned previously largely sample fishes from the open waters of the estuary, including its bays and channel midlines. Accordingly, throughout its range, delta smelt move outside of the survey stations to spawn, making available survey returns less than optimal for addressing delta smelt movements to access the shallow areas and freshwater inlets that all observers agree host spawning by the species.

We differentiated the life history of the delta smelt into five separate life stages—larvae, sub-juveniles, juveniles, sub-adults, and mature adults (Table 1)—based on prior descriptions of the species' life history by Moyle (2002) and Bennett (2005). We chose a 15-mm body length to differentiate between larvae and sub-juveniles, because at 16 to 18 mm delta smelt exhibit more developed fin structure and their swim bladders are filled, making them more mobile within the water column (Moyle 2002). We used 30 mm as the length threshold between sub-juveniles and juveniles, because this size is associated with a change in observed feeding regime (Moyle 2002). We chose 55 mm as the length that differentiates between juveniles and sub-adults or mature adults, because delta smelt growth demonstrably slows between 55 and 70 mm, presumably because most of their available energy is channeled toward gonadal development (Erkkila et al. 1950; Radtke 1966). Because the state of maturation of individual delta smelt is reported in the SKT, we used reproductive stage to (further) subdivide mature adults into pre-spawners and spawners. Delta smelt in reproductive stages 1 to 3 for females, and stages 1 to 4 for males, were classified as pre-spawning adults; reproductive stage 4 in females and stage 5 in males were classified as spawning adults (J. Adib–Samii, CDFW, pers. comm., 2012).

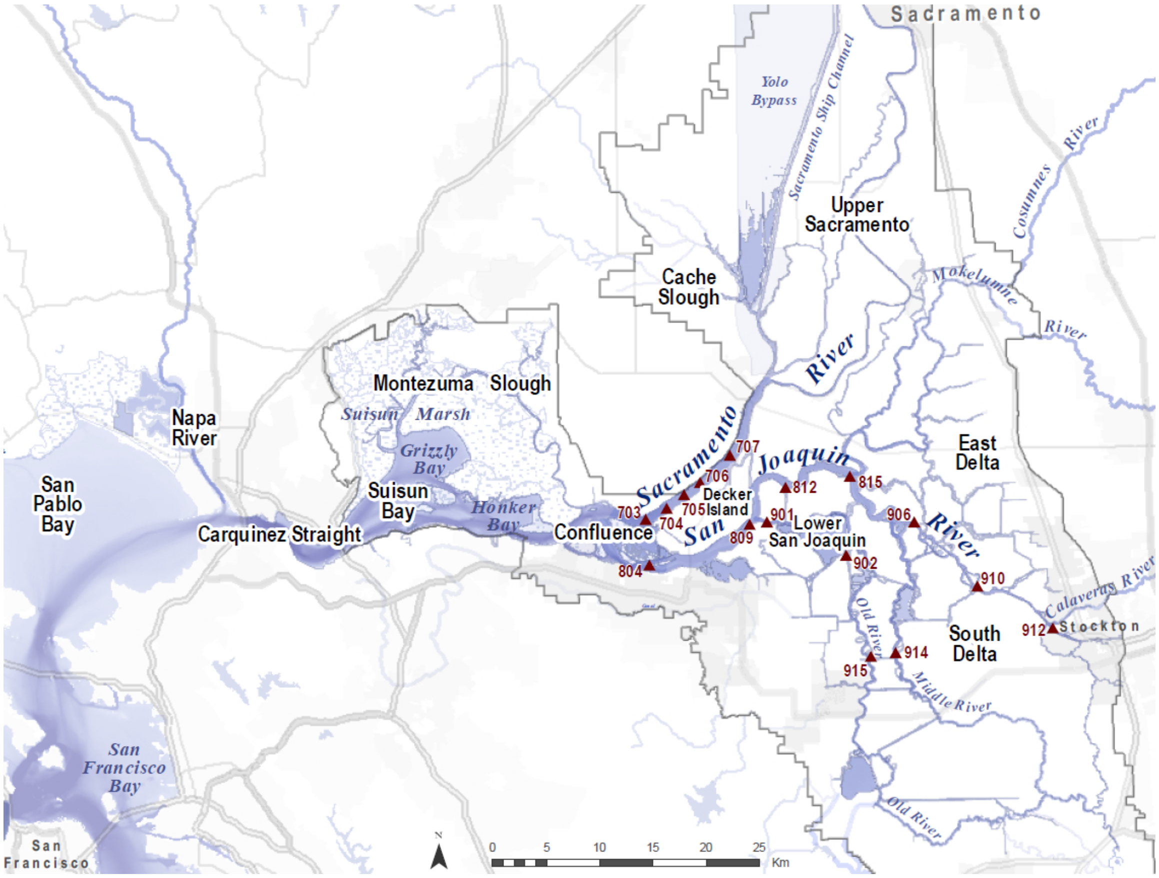

Figure 2 The San Francisco Estuary, including features and geographic designations referenced and described throughout this presentation. Numerical designations accompanying triangles identify trawl survey locations referenced in the text.

Table 1 Delineation of life stages used to examine spatial dispersion of delta smelt. Monitoring program data used for each life stage description (either fish length or reproductive stage), and months and years of sampling data used in our study are described. Gonadal stages of male and female delta smelt found in the Spring Kodiak Trawl database were classified by California Department of Fish and Wildlife (CDFW) following Mager (1986). Descriptions of reproductive stages are available at *http://www.dfg.ca.gov/delta/data/skt/eggstages.asp*

Life stage	Monitoring program	Life stage distinction	Time period	Years of data used in this study
Sub-juveniles	20 mm	≥15, <30 mm	Apr–Aug	1995–2012
Juveniles	20 mm	30 to 55 mm	May–Aug	1995–2012
Juveniles	TNS	30 to 55 mm	Jun–Aug	1987–2011
Sub-adults	FMWT	>55 mm	Sep–Oct, Nov, Dec	1987–2012
Mature adults: pre-spawning	Kodiak Trawl	Reproductive stages: females 1–3, males 1–4	Jan–May	2002–2012
Mature adults: spawning	Kodiak Trawl	Reproductive stages: females 4, males 5	Jan–May	2002–2012
Mature adults: spawning	Beach Seine		Mar–Apr	1987–2009

Although data are available for juvenile and adult delta smelt from the FMWT back to 1967, here we present survey results from 1987 onward in our comparisons of life-stage distributions, concordant with the introduction to the estuary of the Asian clam (*Potamocorbula amurensis*), which is believed to be responsible for major changes in the delta food web (Alpine and Cloern 1992; Greene et al. 2011; Nichols et al 1990; Winder and Jassby 2011). The 20-mm Survey was first conducted in 1995, and was intended to provide data on larval, sub-juvenile, and juvenile delta smelt. Data from the SKT are available from 2002. We have not used data accrued from various supplemental sampling efforts that have recorded delta smelt, because such surveys were conducted for special purposes and were not necessarily consistent with programmatic protocols (R. Baxter, CDFW, pers. comm., 2010). To avoid introducing anomalies that might be caused by the addition of new stations to established survey frames, we only included data from sampling stations that were sampled consistently (that is, stations that were sampled in at least 90% of the years) from any of the monitoring programs.

Distribution by Life Stage

We calculated the average catch per unit effort (CPUE) of delta smelt for each sampling event for each life stage and station by dividing the summed catches C of delta smelt for each life stage l, station s, and time period p in year y by the volume of water in cubic meters V that was sampled for each station and period within a year, then multiplying by 10,000 to determine the catch per 10,000 m^3 for each life stage, region, and year:

$$CPUE_{lspy} = \Sigma C_{lspy} / \Sigma V_{spy} \bullet 1000 \quad (1)$$

Then, we calculated the percentage of delta smelt observed at each station in a year by dividing the result from Equation 1, summed over each station, by the total across all stations in that year (see Table 1). Finally, the average annual percentage of delta smelt for each life stage observed at each station was calculated as a simple average over all years (Table 2). To produce Table 2, the data from the FMWT survey stations were combined and reported for the most proximate 20-mm station.

While recognizing that the gear employed to sample the estuary's fishes varies in terms of catch efficiency, and that catch efficiency varies both between monitoring programs and within samples of each monitoring program (depending on a variety of factors, including the size of individual delta smelt), we did not attempt to adjust the results reported here for catch efficiency. As a result, we draw no conclusions about the census number of delta smelt, which can vary substantially in returns from different monitoring programs and discordantly between life stages from within an individual monitoring program.

Our treatment of delta smelt catch data was limited to the observed distribution, rather than informed by population estimates. The latter would have required estimates of the volumes of the targeted bodies of water and reliance on the assumption that samples are representative of the density of fish throughout the water bodies. The validity of such an assumption may be questionable in a variety of circumstances, particularly when using beach seine data, since the demarcation between "beach habitat" and "open-water habitat" is inherently arbitrary.

To depict spatially the distribution of each life stage across all years sampled, we identified the fewest stations that accounted for 90% of the sampled fish, showing these as dark circles around the relevant station, and the next 9% as light circles. Stations that accounted for less than 0.2% of the observed distribution were not depicted. The extent of the range of each survey is shown as a solid surrounding line. Areas without shading within the surrounding line supported very few delta smelt during the period analyzed.

To test the first hypothesis—that there is unidirectional movement by delta smelt toward eastern spawning areas in the Delta—we looked for a net increase in the percentage of fish east of the Sacramento and San Joaquin rivers confluence (east of stations 703 and 804), from the sub-adult life stage in September and October to the pre-spawning life stage in the subsequent January to May. For this hypothesis (and the second), we considered data from pre-spawning adults rather than spawning adults, having observed that the number of spawning adults sampled was far fewer (80% less) than the number of pre-spawning adults. (Spawning adults presumably move out of deeper, open waters where the monitoring stations are largely located.) We tested the difference between the numbers of delta smelt in the two geographic areas using a one-tailed *t*-test, since the first hypothesis presumes the movement is unidirectional to the east.

To test the second hypothesis—that delta smelt vacate the Suisun bay and marsh complex to spawn in eastern portions of the Delta—we questioned whether the percentage of pre-spawning adults in the area of the Sacramento and San Joaquin rivers confluence and further west (as identified above) were significantly different from zero. We used a one-tailed *t*-test since the percentage could not be negative.

To test the third hypothesis—that sub-juvenile delta smelt are distributed predominantly across the central Delta in the spring—we compared the percentage of sub-juveniles in the central Delta with the percentage of sub-juveniles in all other areas. For this comparison we defined the central Delta to include stations 704 to 711, and 809 to 915. We focused on sub-juveniles, rather than juveniles, because, according to the third hypothesis, juvenile fish should progressively move to the lower Sacramento River and northern Suisun Bay areas. Length measurements of young delta smelt used data from the 20-mm Survey to delineate sub-juveniles (see Table 1), and a one-tailed *t*-test was used to see if the percentage of sub-juvenile delta smelt in the central Delta was significantly greater than 50%.

Percentage data representing delta smelt distributions were arcsin $\sqrt{x}$ transformed before analyses (Zar 2009). Transformed values were checked for normality with a one-sample Kolmogorov–Smirnov test. We used a non-parametric Wilcoxson signed–rank test for data that addressed the second hypothesis, since the data were not transformed to normality. A test for independence of data across years showed no first- or second-order temporal correlation in any of the data series. We ran all *t*-tests (or non-parametric equivalents) as paired tests to account for year effects.

Based on the mapped distribution of delta smelt by life stage and the results of the statistical analyses described above, we generated two synthetic maps, consistent with publicly available survey data, which can be used to represent the locations of delta smelt at two key life stages: (1) juveniles in early summer, as they initiate a protracted period of feeding, growth, and maturation before dispersal to spawning areas, and (2) mature adults at or immediately before spawning, which reflects the maximum extent of the dispersal that they experience associated with movement to spawning areas.

RESULTS

Distribution of Delta Smelt by Life Stage

The distributions of multiple delta smelt life stages are provided in Figures 3 through 7. During summer months the majority of delta smelt feed, grow, and mature in four adjacent geographic locations: in Suisun Bay, in Suisun Marsh (Montezuma Slough), at the Sacramento and San Joaquin rivers confluence, and in the lower Sacramento River (Figure 3). Data from the TNS shows that nearly 90% of the delta smelt sampled in the summer are found in that circumscribed area (Table 2). Delta smelt are essentially absent from the east and south Delta during this period. It should be noted that before 2011, surveys in the summertime did not extend up the Sacramento River to habitat in the Cache Slough complex of river channels in the north, nor north of the mouth of the Napa River.

Delta smelt continue to occupy the same general locations into the autumn, with more than 80% of the sampled fish resident in the same four areas of the estuary through November, and exhibiting a substantial presence in the Cache Slough area (Figure 4). Survey data do, however, suggest some shifts in areas occupied, with increases in the percentages of total delta smelt captured in north Suisun Bay and Montezuma Slough (Table 2). Based on returns from the SKT from January through May, it appears that a trend toward increased delta smelt numbers in areas

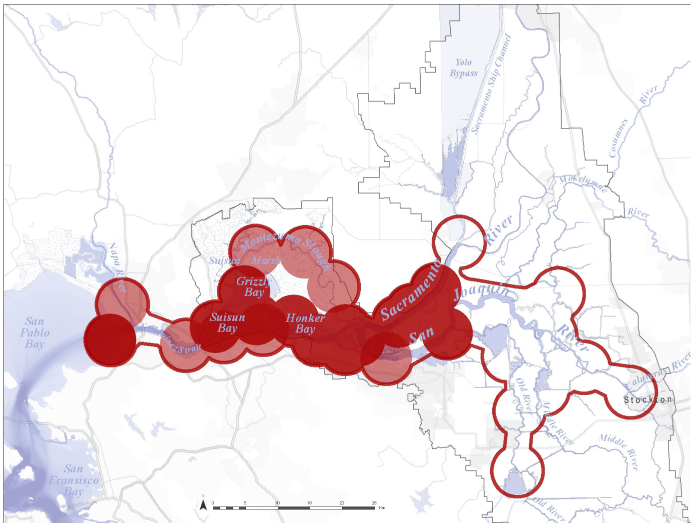

Figure 3 Distribution of delta smelt juveniles in summer (July) in the Summer Townet Survey. Dark circles show survey stations collectively comprising 90% of observed catch. Light circles show next 9% of observed catch. Solid line indicates extent of survey for consistently surveyed stations. A 4-km buffer was used for all stations. Source: CDFW survey data.

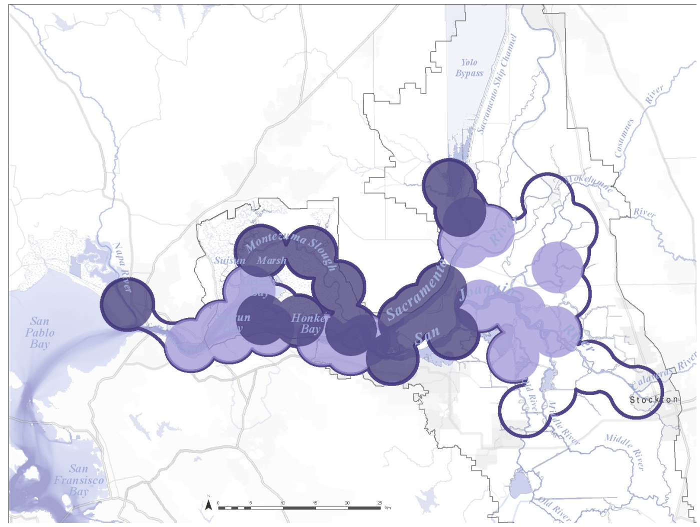

Figure 5 Distribution of delta smelt adults in winter (January to May) in the Spring Kodiak Trawl. Dark circles show survey stations collectively comprising 90% of observed catch. Light circles show next 9% of observed catch. Solid line indicates extent of survey for consistently surveyed stations. A 4-km buffer was used for all stations. Source: CDFW survey data.

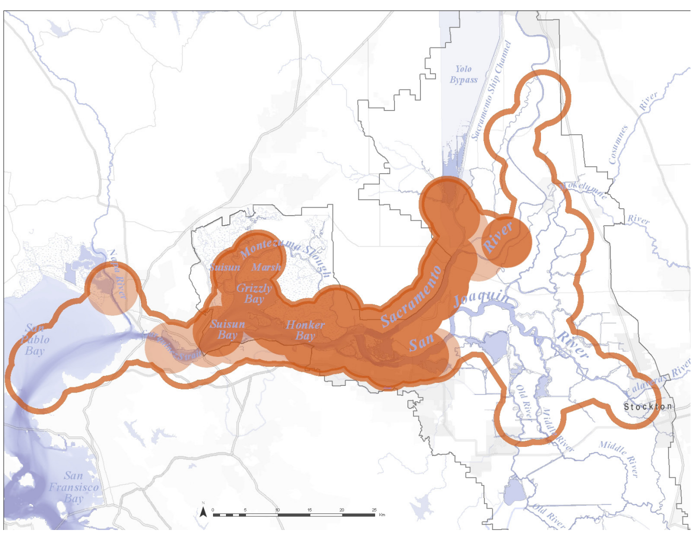

Figure 4 Distribution of delta smelt sub-adults in fall (September to November) in the Fall Midwater Trawl Survey. Dark circles show survey stations collectively comprising 90% of observed catch. Light circles show next 9% of observed catch. Solid line indicates extent of survey for consistently surveyed stations. A 4-km buffer was used for all stations. Source: CDFW survey data.

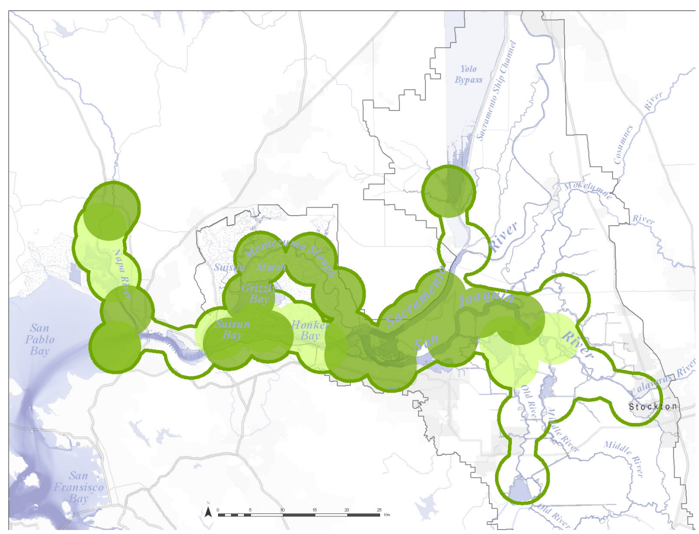

Figure 6 Distribution of delta smelt sub-juveniles in spring (April to June) in the 20-mm Survey. Dark circles show survey stations collectively comprising 90% of observed catch. Light circles show next 9% of observed catch. Solid line indicates extent of survey for consistently surveyed stations. A 4-km buffer was used for all stations. Source: CDFW survey data..

beyond the four summer population loci continues, and expands through the winter and into the spring, with occurrences and numbers beyond the mid-year core areas in all compass directions. In the winter and spring, delta smelt extend to the northwest into the Napa River, are more frequent north in Suisun Marsh, are found to the northeast further up into the lower Sacramento River, are frequent in the Cache Slough area, and can be found in small numbers in the eastern Delta, including the lower San Joaquin River (Figure 5).

Approximately 80% of pre-spawning adults are sampled from just three areas: Montezuma Slough, the lower Sacramento River, and the Cache Slough complex (Table 2). Spawning adults in the SKT are generally observed in the same locations as their pre-spawning predecessors, although there are 80% fewer spawners than pre-spawners observed in the SKT, suggests that some of the fish have moved away from open-water survey sites. Data from the beach seine surveys suggest that adults are found beyond the boundaries of the SKT, with observations of delta smelt well up the Sacramento River. The differences between the two surveys suggest that the mid-channel SKT under-samples spawning adults.

Data derived from beach seine surveys indicate that a northerly dispersal of spawning delta smelt adults is more frequent than dispersal in east or southeast directions (Figure 7), with just incidental observations along the San Joaquin River. The sub-juveniles produced by the spawning adults are dispersed widely throughout the Delta (Figure 6), frequently to the limit of the range of monitoring, suggesting the reasonable possibility that more individuals exist beyond the geographic range depicted here. However, by summer (June and July), juveniles appear to have retreated to and are concentrated in areas where they will remain for the following 6 months: north and south Suisun Bay, the Sacramento and San Joaquin rivers confluence, and the lower Sacramento River, particularly around Decker Island, and notably, in the Cache Slough complex of channels.

The lack of a consistent and comprehensive spatial overlap in the five fish surveys leaves several select points of delta smelt distribution and dispersal unre-

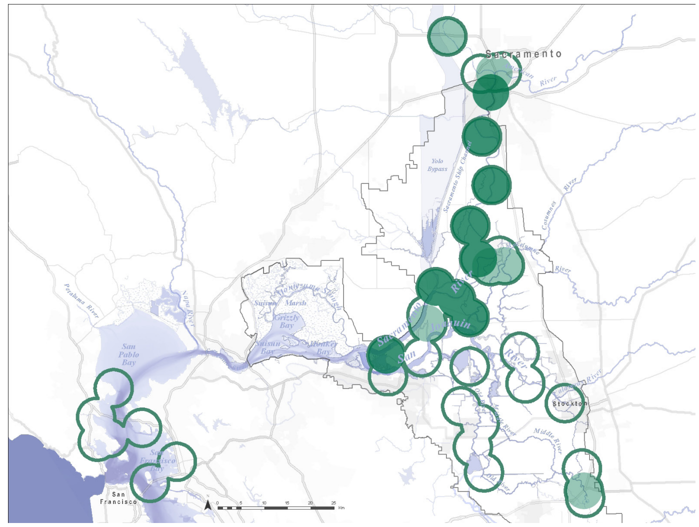

Figure 7 Distribution of delta smelt adults in spring (March to April) from the Beach Seine Survey. Dark circles show survey stations collectively comprising 90% of observed catch. Light circles show next 9% of observed catch. Solid line indicates extent of survey for consistently surveyed stations. A 4-km buffer was used for all stations. Source: USFWS survey data.

solved by available data. We use inference, however, to interpret those information gaps. We can infer delta smelt occupancy of the Cache Slough area at the upper northeastern end of the range of the species: on average 12% of the sub-adults in September and October were sampled there. Since those months precede the redistribution of adults for spawning, and since Cache Slough was not routinely surveyed in the historical TNS, it might be reasonably concluded that a year-round "population" of delta smelt exists in near-freshwater circumstances in the Cache Slough area (Sommer et al. 2011). The question of year-round occupancy of the Napa River is uncertain, because neither the TNS nor the FMWT samples upper reaches of the Napa River. Data from the 20-mm Survey indicate that spawning occurs well up the Napa River, but the lack of data from other surveys prevents us from concluding a year-round delta smelt presence there.

When the five maps (Figures 3–7) are considered together, it is evident that a wide-ranging population—or a collection of (likely) interacting demographic units—of delta smelt can be found year-round

Table 2 Average distribution of delta smelt observed in Interagency Ecological Program monitoring surveys by location. Source: *http://www.dfg.ca.gov/delta/data/20mm/stations.asp*

Life-stage	Sub-juvenile	Juvenile	Juvnile	Sub-adult	Sub-adult	Sub-adult	Prespawn Adult	Spawning Adult	Adult	Spawning Adult
Period	All	All	Jun-Aug	Sep-Oct	Nov	Dec	Jan-May	Jan-May	Mar-Apr	
Survey	20mm	20mm	STN	FMWT	FMWT	FMWT	Kodiak	Kodiak	Beach Seine	Combined
San Pablo Bay										
323	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%				
Napa River										
340	1.3%	0.5%	0.9%	0.0%	0.0%	0.0%	2.0%	4.3%		2.7%
342	0.5%	0.7%								
343	1.2%	0.7%								
344	1.0%	0.7%								
345	2.3%	1.3%								
346	3.4%	1.6%								
Subtotal	9.7%	5.5%	0.9%	0.0%	0.0%	0.0%	2.0%	4.3%		2.7%
Carquinez Straight										
405	0.2%	1.9%	1.8%	1.6%	0.0%	0.1%	0.2%	0.0%		0.0%
411	1.5%	1.8%	0.7%	0.8%	0.4%	0.3%	0.4%	0.1%		0.1%
418	0.3%	1.1%	2.1%	2.2%	2.2%	0.5%	0.3%	0.4%		0.2%
Subtotal	1.9%	4.9%	4.6%	4.7%	2.6%	0.9%	0.9%	0.5%		0.3%
South Suisun Bay										
501	0.7%	2.9%	3.5%	1.5%	1.5%	6.8%	1.8%	0.3%		0.2%
504	2.5%	1.0%	1.7%	2.0%	0.3%	0.6%	0.6%	0.2%		0.1%
508	1.9%	3.6%	5.8%	6.9%	2.8%	2.4%	1.1%	0.6%		0.4%
Subtotal	5.1%	7.5%	11.0%	10.4%	4.6%	9.8%	3.5%	1.2%		0.7%
Montezuma Slough										
606	3.6%	1.5%	0.8%	2.9%	7.6%	15.7%	21.7%	14.9%		9.4%
609	5.2%	1.7%	1.3%				26.6%	10.6%		6.7%
610	3.8%	1.5%	0.9%	0.2%	0.2%	1.5%	2.1%	1.4%		0.9%
Subtotal	12.5%	4.7%	3.0%	3.1%	7.8%	17.3%	50.4%	26.9%		17.0%
North Suisun Bay (including Grizzly & Honker Bays)										
513	3.6%	6.2%	9.6%	9.1%	8.8%	4.6%	1.2%	1.9%		1.2%
602	3.6%	16.2%	13.3%	4.1%	1.2%	4.1%	1.4%	0.5%		0.3%
519	1.8%	7.0%	6.5%	2.9%	7.3%	16.0%	4.9%	2.5%		1.6%
Subtotal	9.0%	29.4%	29.4%	16.1%	17.3%	24.7%	7.5%	5.0%		3.1%
Confluence										
520	3.8%	2.3%	1.9%							
703	7.1%	7.3%		10.3%	8.4%	6.5%			1.5%	0.6%
801	2.8%	1.7%	2.4%	1.3%	0.4%	0.2%	0.8%	0.3%		0.2%
804	3.4%	0.9%	1.5%	0.5%	0.5%	0.1%	0.9%	0.2%	0.0%	0.1%
Subtotal	17.1%	12.2%	5.8%	12.1%	9.3%	6.7%	1.7%	0.6%	1.5%	0.9%
Lower Sacramento River (Decker Is)										
704	9.8%	16.5%	20.6%	15.2%	16.3%	9.7%	8.1%	8.0%		5.0%
705	1.9%	0.5%								
706	11.4%	9.7%	16.7%	17.8%	18.6%	13.8%	6.5%	2.3%		1.5%
707	3.8%	1.5%	5.7%	6.1%	13.3%	7.0%	2.7%	9.2%	27.2%	16.5%

Table 2 Average distribution of delta smelt observed in Interagency Ecological Program monitoring surveys by location (Cont.)

Life-stage	Sub-juvenile	Juvenile	Juvnile	Sub-adult	Sub-adult	Sub-adult	Prespawn Adult	Spawning Adult	Adult	Spawning Adult
Period	All	All	Jun-Aug	Sep-Oct	Nov	Dec	Jan-May	Jan-May	Mar-Apr	
Survey	20mm	20mm	STN	FMWT	FMWT	FMWT	Kodiak	Kodiak	Beach Seine	Combined
Cache Slough Complex										
711	0.1%	0.0%	0.0%	5.2%	1.4%	3.4%	0.2%	3.5%	10.6%	6.3%
712							0.0%	0.5%		0.3%
713							1.0%	4.5%		2.9%
715							4.0%	9.5%		6.0%
716	5.5%	6.5%		7.3%	5.2%	2.7%	7.2%	18.1%	5.7%	13.7%
719										
798										
Subtotal	5.6%	6.5%	0.0%	12.4%	6.6%	6.1%	12.3%	36.1%	16.3%	29.2%
Upper Sacramento										
717									5.5%	2.2%
724									2.2%	0.9%
735									4.8%	1.9%
736									11.6%	4.5%
749									19.0%	7.5%
Subtotal							0.0%	0.0%	43.1%	16.9%
Lower San Joaquin River										
802				1.6%	2.0%	1.4%				0.0%
809	5.4%	0.7%	1.8%	0.2%	1.0%	1.8%	2.8%	2.9%	0.0%	1.8%
812	1.8%	0.1%	0.1%	0.1%	0.6%	0.4%	0.6%	1.5%		1.0%
815	1.9%	0.0%	0.2%	0.0%	0.0%	0.0%	0.3%	1.0%		0.6%
Subtotal	9.1%	0.8%	2.1%	1.9%	3.6%	3.7%	3.7%	5.5%	0.0%	3.4%
South Delta										
901	0.8%	0.1%								
902	0.7%	0.1%		0.0%	0.0%	0.0%	0.2%	0.3%	0.0%	0.2%
914	0.3%	0.0%		0.0%	0.0%	0.0%			0.0%	0.0%
915	0.2%	0.0%		0.0%	0.0%	0.0%			0.0%	0.0%
918	0.2%	0.0%		0.0%	0.0%	0.0%				
Subtotal	2.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.2%	0.3%	0.0%	0.2%
East Delta										
906	0.5%	0.0%		0.0%	0.0%	0.0%			0.1%	0.0%
910	0.1%	0.1%		0.0%	0.0%	0.0%			0.1%	0.0%
912	0.0%	0.1%		0.0%	0.0%	0.0%			0.0%	0.0%
919	0.2%	0.1%		0.0%	0.0%	0.0%			0.2%	0.1%
920										
921										
922									2.5%	1.0%
923									4.2%	1.6%
Subtotal	0.9%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.0%	2.8%
Total	100%	100%	100%	100%	100%	100%	99%	100%	95%	100%

in several areas of the Delta: north Suisun Bay, the Sacramento and San Joaquin rivers confluence, the lower Sacramento River (around Decker Island), and in and adjacent to Cache Slough. The data used to generate those maps allow the first hypothesis—that delta smelt move in an easterly direction from Suisun Bay at the onset of spawning—to be addressed. The percentages of sub-adult delta smelt in the early fall (September and October) and pre-spawning adults that are located east of the Sacramento and San Joaquin rivers confluence are reported in Table 3. Rather than supporting the hypothesis that the relative abundance of delta smelt east of the rivers' confluence increases with fish there maturing to spawning condition, the percentage of the surveyed population there actually decreases; with an average of 24% fewer delta smelt later in their life cycle being detected in surveys east of the confluence (with the west–east difference significant at the 95% level).

We addressed the second hypothesis—that delta smelt vacate Suisun Bay and the Sacramento and San Joaquin rivers confluence before spawning—by testing whether the percentage of pre-spawning delta smelt that reside at the rivers' confluence or to the west, was not significantly different from zero. The presence of pre-spawning delta smelt at the rivers' confluence and west of it averages 67%, which is significantly different from zero at the 95% level (Table 4). We can reject the hypothesis that delta smelt vacate the western portion of the estuary to spawn.

We also rejected the third hypothesis: that sub-juvenile delta smelt are found predominantly in the central Delta. Data from the 20-mm Survey from 1995 to 2009 show that, on average, 39% of sub-juveniles were found in the central Delta, with the remaining 61% found in other locations (Table 5). Moreover, even the finding that 39% of sub-juvenile delta smelt are present in the central Delta might be viewed as misleading. Stations 704, 705, 706, and 707 are located in the lower Sacramento River, from Decker Island downstream to the confluence (see locations in Figure 2). As observed on the series of maps (Figures 3–7), delta smelt are typically located in this area year-round; therefore, much of their presence in the central Delta is not likely to be the result of seasonal dispersal to that area. Also, the area is on the very northwest edge of the Delta, and is not usually considered part of the central Delta. Removing these

Table 3 Percentage of delta smelt sub-adults sampled east of the confluence in September and October in the FMWT compared with the percentage of pre-spawning adults in the subsequent SKT

Cohort Year	Percentage east of confluence during Sep–Oct in FMWT	Percentage east of confluence during subsequent Jan–May in SKT	Percent change
2001	90.9%	18.1%	–72.8%
2002	52.7%	61.4%	8.7%
2003	83.3%	17.2%	–66.1%
2004	93.3%	28.2%	–65.1%
2005	76.0%	18.4%	–57.6%
2006	40.9%	26.2%	–14.7%
2007	23.8%	75.3%	15.5%
2008	73.3%	57.6%	–15.7%
2009	62.5%	2.0%	–60.5%
2010	34.1%	27.6%	–6.5%
2011	4.7%	35.8%	31.1%
Average	57.8%	33.4%	–24.4%
Std. Dev.	29.1%	22.2%	43.1%

Table 4 Percentage of delta smelt pre-spawning adults located at the confluence and west of it in the SKT

Year	Pre-spawning adults Jan–May
2002	81.9%
2003	38.6%
2004	82.8%
2005	71.8%
2006	81.6%
2007	73.8%
2008	24.7%
2009	42.4%
2010	98.0%
2011	72.4%
2012	64.2%
Average	66.6%
Std. Dev.	22.2%

four stations from the central Delta station grouping used in Table 5, reduces the average observed presence of delta smelt in the actual central Delta from 39% to just 12%.

Collectively, rejecting the three hypotheses strongly supports the perspective that delta smelt spawning movement is multi-directional—likely toward local freshwater inputs—rather than manifest as a uni-directional eastward migration.

A pair of synthetic maps depicts inter-seasonal dispersal by delta smelt (Figures 8A and 8B). Juvenile delta smelt are found primarily in four areas in late spring: (1) in the Napa River estuary, (2) in areas from the western portion of Grizzly Bay through Suisun Bay to the Sacramento and San Joaquin rivers confluence, including Montezuma Slough and likely other larger channels in and about Suisun Marsh, (3) in areas along the lower Sacramento River extending up to and beyond the complex of small embayments and channels around Cache Slough and Liberty Island, and (4) perhaps further north upstream in the Sacramento Deep Water Ship Channel. Delta smelt adults, just before and into the period of spawning, exhibit a distribution at relatively high densities:

Table 5 Percentage of delta smelt sub-juveniles located in the central Delta, using data from the 20-mm Survey and life stage delineations from Table 1

Year	Central Delta Stations 704–711, 809–915
1995	2.3%
1996	8.8%
1997	69.4%
1998	1.2%
1999	29.1%
2000	33.8%
2001	85.4%
2002	70.3%
2003	34.7%
2004	69.4%
2005	6.9%
2006	1.4%
2007	77.2%
2008	80.0%
2009	59.7%
2010	33.5%
2011	1.0%
2012	31.9%
Average	38.7%

(1) from the area around Suisun Bay and adjacent to Montezuma Slough, and (2) east up the lower Sacramento River into the area of Cache Slough and Liberty Island; and in lesser densities, (3) in the San Joaquin River and its more northern tributaries, (4) in Montezuma Slough in Suisun Marsh, and (5) in the lower Napa River and its estuary. An east–west distributional disjunction between younger and older delta smelt in the Delta is not apparent; lesser shifts are apparent in the distribution of delta smelt within its geographic range between life stages.

DISCUSSION

Five trawl-based fish surveys sample extensive, partially overlapping portions of the Sacramento–San Joaquin River Delta and adjacent areas of the San

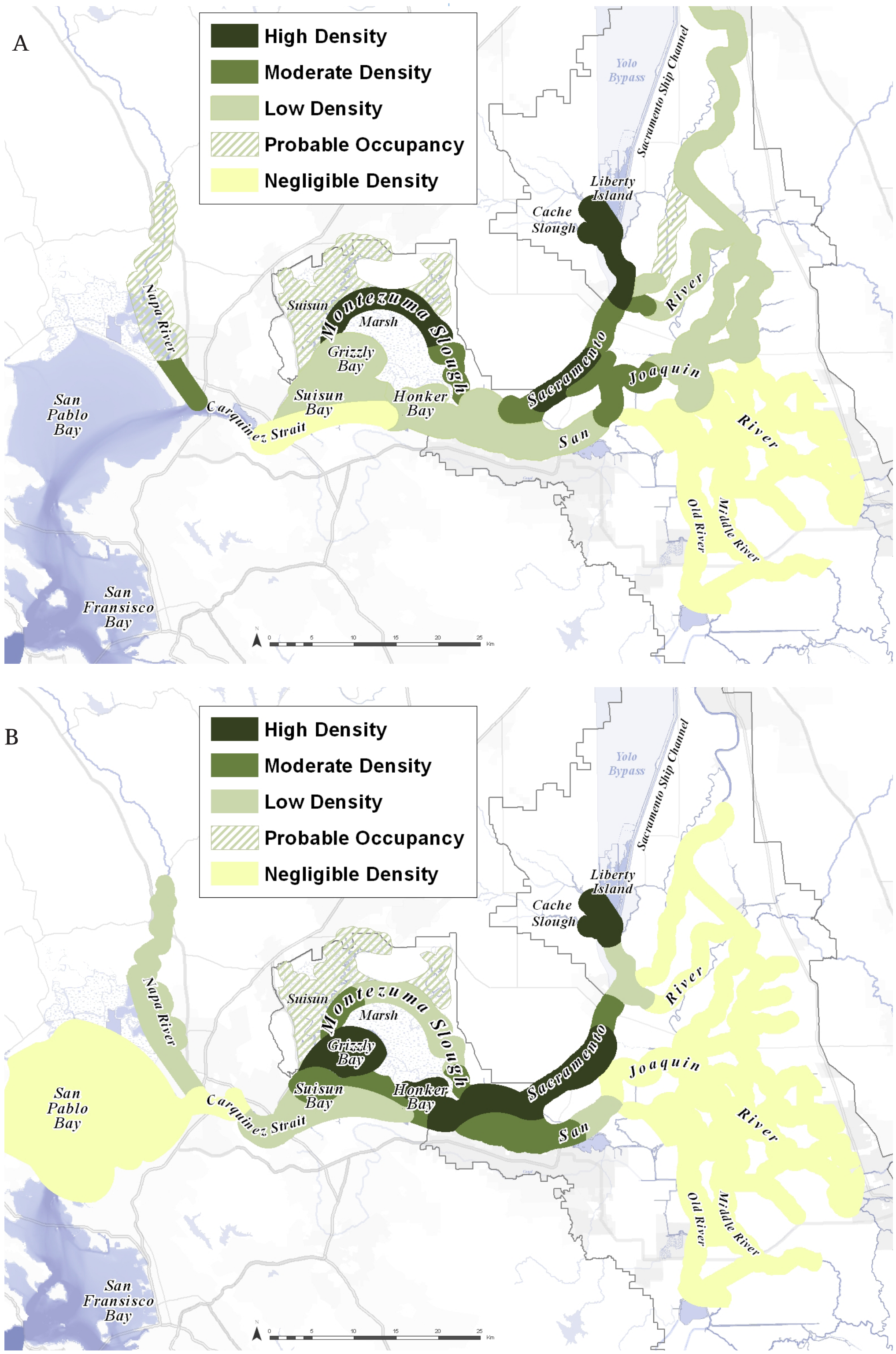

Figure 8 Synthesized distribution of delta smelt in summer and fall (**A**) before dispersal to spawning areas, and in spring (**B**) after dispersion. The dark areas show the predominant range during each period. The high and moderate density areas combined account for 90%, on average, of the observed presence of delta smelt. Areas of negligible density combined account for less than 1% of delta smelt during the survey period. Light green areas represent 9% of the presence of delta smelt. Source: CDFW survey data.

Francisco Estuary. The known distributional range of delta smelt has been informed largely by those surveys (Merz et al. 2011). Delta smelt range from the just east of the Carquinez Strait, through Grizzly and Suisun bays, and the adjacent Suisun Marsh, up-Delta past the Sacramento and San Joaquin rivers confluence, on the lower Sacramento River, in the Cache Slough and Liberty Island complex of waterways, and in the Sacramento Deep Water Ship Channel. Beach Seine surveys have established that delta smelt are present in the Sacramento River north of Walnut Grove. Occasional individuals can be found in eastern, southeastern, and southern portions of the Delta in the winter and spring; and very young juvenile delta smelt may be rather widely distributed across the Delta before settling into a largely northern and western Delta distributional range. Delta smelt have also been observed as a disjunct presence in lower reaches of the Napa River.

The pertinent issue addressed here is the distribution of delta smelt adults before spawning and their movement to locations at which spawning presumptively occurs. Two alternative perspectives have been offered regarding movement by delta smelt from "rearing" areas to spawning locations. One describes a uni-directional, upstream migration by delta smelt from rearing areas in the west Delta to freshwater areas in the east. The other describes a diffuse dispersal from embayments and channels across the northern Delta, marshward to adjacent shoals and shorelines, where upland freshwater from winter and spring storms is delivered into Delta waters. The two perspectives inform our understanding of what constitutes habitat for delta smelt—its spatial extent, and its temporal patterns of habitat occupancy—as well as determining the conservation actions that might benefit delta smelt, prioritizing those actions, and identifying the locations where management actions might yield the greatest benefits to delta smelt.

Our analyses using data generated by seasonal surveys refute the assertion that delta smelt undertake uni-directional movement in late autumn and early winter toward eastern spawning areas in the Delta. Spatial data are consistent with delta smelt dispersal from bay, embayment, and channel areas occupied by pre-spawner delta smelt toward freshwater inlets on nearby shores and in marshes, with only a relatively small fraction of delta smelt exhibiting movement east to freshwater, including up and into the Sacramento or San Joaquin rivers. The mapped survey data indicate that most of the delta smelt that rear in Suisun Bay appear to disperse north to Montezuma Slough and Suisun Marsh to spawn. Fish in the Cache Slough complex of channels and wetlands appear to stay in that general area. And delta smelt in the lower Sacramento River likely disperse in multiple directions: up the Sacramento River, east toward the San Joaquin River, and west into Montezuma Slough. Drawing from Table 2, the percentage of delta smelt sampled in Suisun Bay decreased from 34.5% in December to 11% in January through May, whereas the percentage in Montezuma Slough increased from 17.3% in December to over 50% in January through May. In September and October, 12.4% of sampled delta smelt were sampled from the Cache Slough complex; that percentage declined in November and December, but rebounded to 12.3% for the period from January through May. Given the spatial and temporal patterns of delta smelt in survey samples, it is likely that many pre-spawning delta smelt move inshore and out of the range of institutional monitoring surveys; but, survey data indicate that most adults that are ready to spawn remain in these same three general geographic areas. The data presented here contradict the depiction of delta smelt vacating the Grizzly Bay and Suisun Bay areas and the adjacent Suisun Marsh complex of wetlands to spawn in eastern portions of the Delta. In addition, survey returns appear to counter the assertion that sub-juvenile delta smelt are more frequent across the central Delta in the spring, rather than in northern portions of the estuary. Nearly two-thirds of young juvenile fish come from survey stations from Decker Island downstream to the Sacramento and San Joaquin rivers confluence in the spring. This finding is consistent with earlier observations of the distribution of young fish. Citing Radtke (1966) and Wang (1986), 2 decades ago, Moyle et al. (1992) reported "spawning apparently occurs along the edges of the rivers and adjoining sloughs in the western Delta."

In sum, life-stage-specific distribution maps generated from multiple, seasonal trawl surveys that regularly capture delta smelt do not show the sort of annual, large-scale, population-wide migration event by delta smelt as has been described by the OCAP Technical Support Team (unpublished) and U.S. Bureau of Reclamation (2012). The most parsimonious conclusion that can be drawn from surveys that sample delta smelt before, during, and after the winter to early spring spawning period is that the fish move from open water to adjacent shoals and shoreline areas, which exhibit the physical attributes—especially the freshwater inputs and appropriate substrates—that are necessary to support successful spawning.

Sommer et al. (2011) also describe the annual dispersal patterns of delta smelt. Their study computes the average position of delta smelt in temporal samples (the centroid of the distribution of the fish) from a subset of FMWT stations, and suggests that the "population" centroid moves slightly east in the very late autumn in relation to the location of the dynamic low-salinity zone in the estuary. This is interpreted as evidence of upstream migration. The findings presented here call into question use of the centroid of the distribution of delta smelt to assess their inter-seasonal movement. The west-to-northeast orientation of the Delta's uplands interface and channel complexes that delta smelt occupy can provide for an eastward component to fish spawning movements that could also be inshore, north (or south) toward freshwater inputs. Moreover, the presence of multiple demographic loci obviates the utility of defining a single delta smelt centroid, the geographic shifting of which can misrepresent actual site-specific movement patterns. But, perhaps most importantly, the slight eastward shifts in the centroid of the delta smelt distribution described by Sommer et al. (2011) do not support the assertion that delta smelt undergo a mass migration to the freshwater edge of the Delta—even a substantial shift in the distributional centroid of delta smelt with the onset of spawning would leave a large fraction of the fish far from the freshwater limits at the Delta's eastern boundary. As support for an eastward, "upstream" migration by delta smelt, Sommer et al. (2011) turn to previous studies for corroboration (Swanson et al. 1998; Dege and Brown 2004), but neither of those studies offer data or analyses that address the issue of migration *per se*.

Use of the term "migration" to characterize seasonal, spawning-related movements in delta smelt without presentation of an unambiguous definition of the term may have contributed to a confounded narrative about seasonal delta smelt movements. The federal resource agency maps presented herein illustrate movement phenomena that meet the vernacular use of the term "migration," with fish moving extensive distances across the Delta to reproduce. And, Sommer et al. (2011) used the term in their description of a long-distance west-to-east dispersal phenomenon. But, Moyle (2002) and Bennett (2005) also referred to migration in describing delta smelt moving from open waters to adjacent shorelines—a less commonplace use of the term. In strict technical usage, both short- and long-distance dispersal can constitute migration (Dingle and Alistair Drake 2007; Lack 1968; Ramenofsky and Wingfield 2007). Wilcove (2007) differentiates migratory movements from "daily searches for food and shelter" or "the dispersal movements of offspring, as they establish their own territories." Hence, while the term migration conjures up for many a picture of songbird flights from boreal forests to far-distant tropical winter refuges, it is also technically correct to invoke the term migration to describe the delta smelt's far less ambitious dispersal from open waters to adjacent shorelines. Nonetheless, we have used the term "dispersal" to reflect the seasonal movement of the fish between rearing and spawning areas, and to differentiate such movements from the long-distance, uni-directional movements that are essential to the conceptual model employed by the federal resource agencies (OCAP Technical Support Team unpublished; USBR 2012).

The findings presented here on seasonal dispersal have implications for understanding delta smelt ecology and behavior. An annual, east–west migration of delta smelt would serve to provide contact among and mixing of individuals into a single (truly) panmictic population. But, with the presence of four or more geographically discontinuous delta smelt spawning loci in the Delta, as indicated here, and absent mass directional movements, a different demographic picture can be inferred. Substantial demographic mixing is certain in the limited-dispersal scenario. This is consistent with Hobbs et al. (2007), who used trace elemental fingerprinting to determine natal areas of delta smelt. Under a limited-dispersal model, at least within each generation, exchange of individuals from areas of the western Delta (Suisun Bay and marshes) and eastern Delta (Cache Slough and neighboring areas) is constrained; while the stepping-stone exchange necessary to genetically tie the demographic units of delta smelt east of the Carquinez Strait is realized (see Fisch et al. 2011).

In light of the spatial and temporal patterns of delta smelt distribution presented here, characterization of delta smelt habitat is possible. Extensive areas depicted as being seasonally occupied in the federal agency maps, and hence providing habitat for delta smelt, appear to support a very small fraction of the overall numbers of the species, and then only for limited periods of the year (and see Figure 4 in Merz et al. 2011). According to survey data, much of the area in the large eastern polygons in Figures 1A and 1B are infrequently occupied and currently may not provide habitat for delta smelt. At the same time, some areas of the west Delta, which have explicitly been considered to have limited or intermittent habitat quality (see Armor et al. 2005), appear to host delta smelt that are preparing to spawn, and those areas and adjacent channels appear to be more consistently occupied by delta smelt that previously described.

These observations have implications for delta smelt conservation and for resource managers. The distribution of delta smelt during each of the life stages serves to delineate the suite of environmental stressors that may affect them. That a substantial portion of the estuary's delta smelt spawners are found in Suisun Marsh, but a small fraction of the youngest delta smelt are subsequently there, suggests that environmental stressors in that area need to be closely examined. An ambitious effort to restore tidal marshes and wetlands in the Delta, which are believed to contribute to producing prey for delta smelt, has targeted candidate locations for habitat restoration efforts (BDCP 2013). Available distribution data and the dispersal phenomena that can be inferred from them strongly suggest that marshland restoration efforts would be best directed and prioritized to areas within and between the loci of delta smelt occurrences in the north Delta. The lack of evidence that delta smelt make an extensive easterly migration to spawn could inform the selection of locations (and prioritization) for restoration targets, with recognition that efforts to construct or rehabilitate habitats for delta smelt should be designed to support local demographic units, not seasonal migrants.

The maps presented here indirectly address Sommer et al.'s (2011) concern about the effects that entrainment of delta smelt at water export facilities in the south Delta may have on the species' status and trends. They also indicate that conclusions about population-level effects of entrainment at export pumps may warrant re-evaluation (see Grimaldo et al. 2009). While salvage samples at export pumps demonstrate that delta smelt are at least intermittently entrained, the assertion that mortality from entrainment is frequently large or is sporadically so (see Kimmerer 2008, 2011; Miller 2011), and therefore consequential to the status and trends of delta smelt, is not so clear (see also Castillo et al. 2012). While available distribution data suggest relatively wide dispersal of larvae and young juvenile delta smelt away from natal spawning areas—and hence some proportion of the very youngest delta smelt may be lost at the water export pumps—available survey data do not seem to support the contention that large numbers of delta smelt migrating upstream pass perilously close to the export facilities or are drawn to them during annual, long-distance spawn movements.

CONCLUSIONS

Using available survey data, we have presented a complex picture of the distribution and dispersal of delta smelt before spawning. A diffuse collection of delta smelt population loci exist in and adjacent to the northern Delta's open waters, individuals from which undertake landward movements to spawn. These movements are consistent with the long-understood idea that delta smelt mature in the estuary's brackish water and spawn in fresher water. The maps offer no support for a uni-directional, easterly spawning migration by delta smelt from open water in the west of the Delta to fresher water to the east. The alternative conceptual model of delta smelt spawning movements described here, and supported by earlier studies and inferences, indicates a need to re-evaluate the relative importance of the environmental stressors that are reducing the numbers of delta smelt—and the appropriate recovery measures that should be taken in efforts to conserve the species.

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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:

- <u>Green sturgeon</u>: 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.

- <u>Splittail</u>: 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.

- <u>Starry flounder</u>: 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.

- <u>American shad</u>: 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).

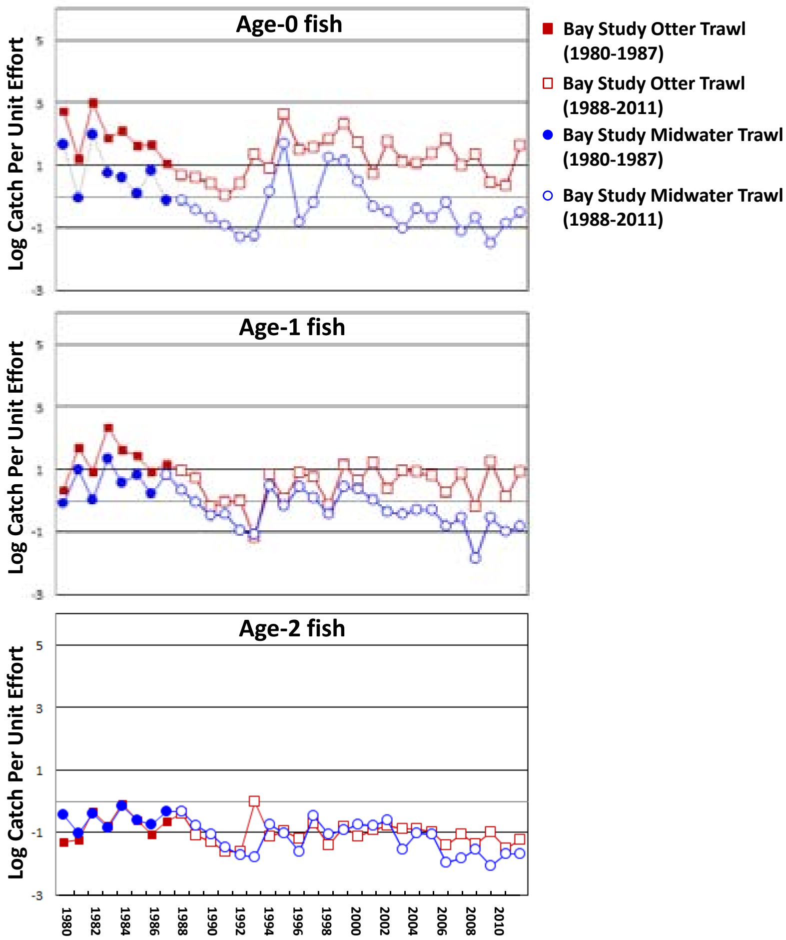

Figure 1. Bay Study Otter Trawl (boxes) and Midwater Trawl (circles) catch per unit effort. Age-0 and age-1 fish catch is greater in the Otter Trawl, which samples near the bottom, than the Midwater Trawl, indicating that many fish are more demersal than pelagic. Age-2 fish are more pelagic. Otter Trawl 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.

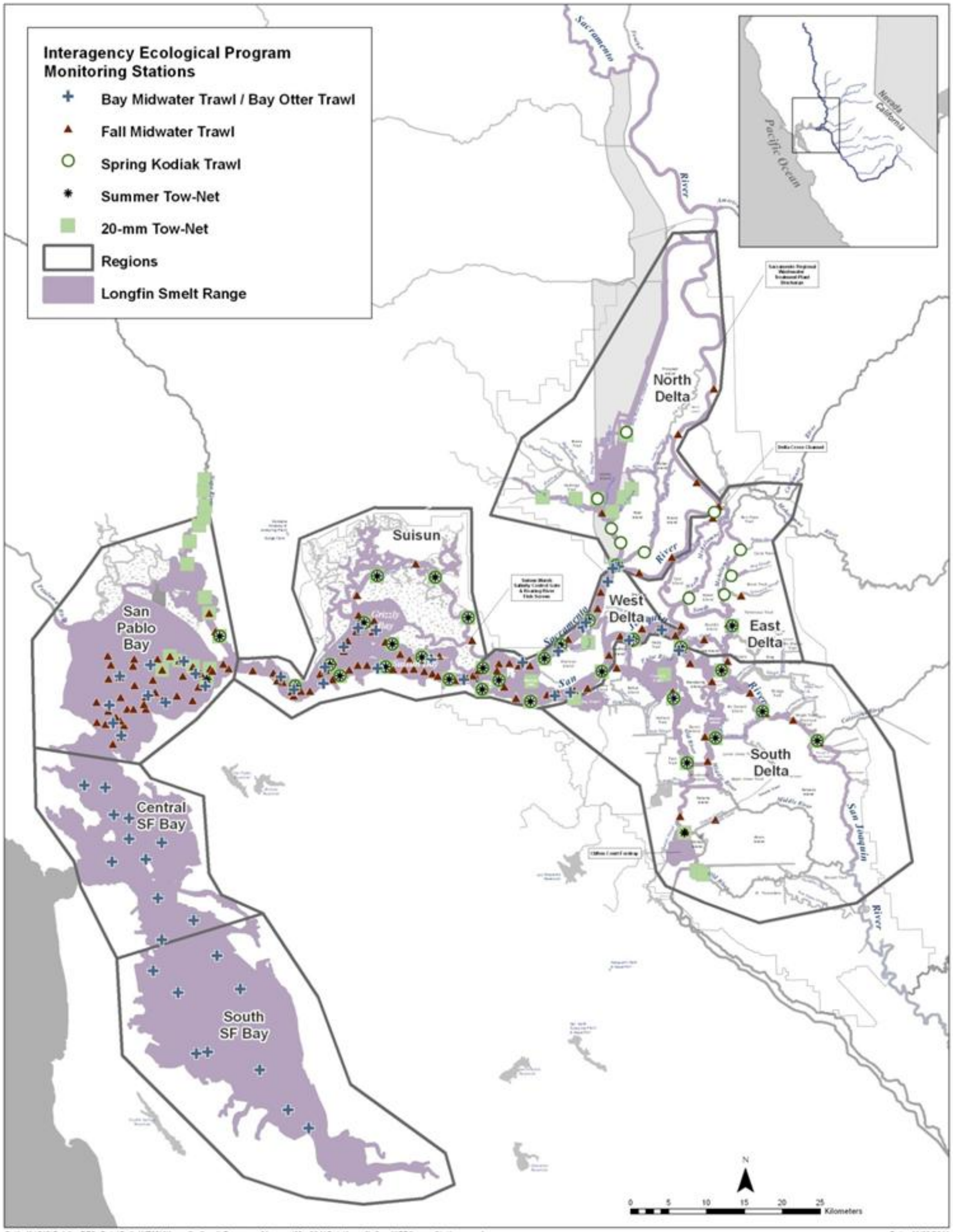

Figure 2. Extent of Interagency Ecological Program monitoring stations. The Fall Midwater Trawl does not extend into Central and South Bays while the Bay Study trawls do. The Bay Study trawls demonstrate that longfin smelt's known range in the estuary extends into these bays. From Gray et al. (in prep).

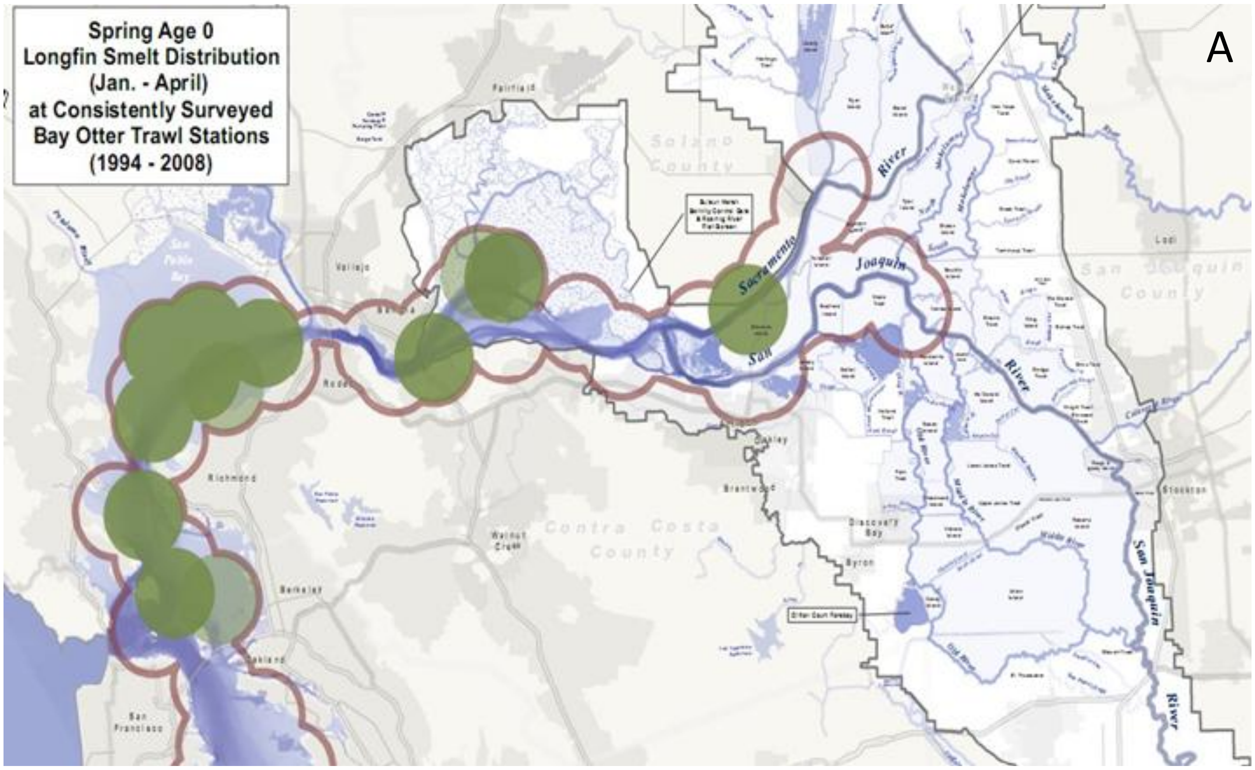

Figure 3A. Spring distribution of longfin smelt in the Bay-Delta system based on catch per unit effort. (A) Age-0 fish. Note, the dark shaded circles represent 90% of the effort adjusted catch (major catch) and the light circles indicates the <9% effort adjusted catch (minor catch). Longfin smelt are 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

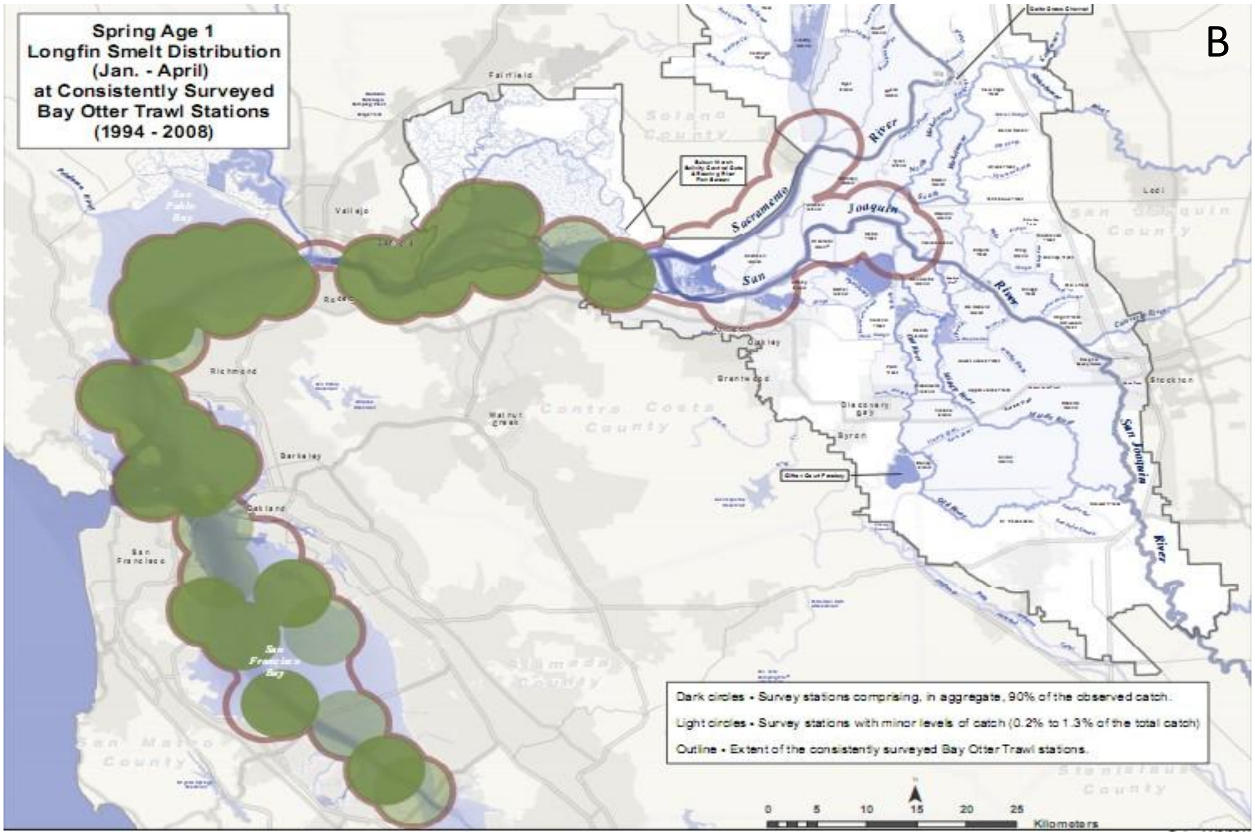

Figure 3B. Spring distribution of age-1 longfin smelt in the Bay-Delta system based on catch per unit effort. Note: the dark shaded circles represent 90% of the effort adjusted catch (major catch) and the light circles indicates the <9% effort adjusted catch (minor catch). Age-1 longfin smelt are found 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

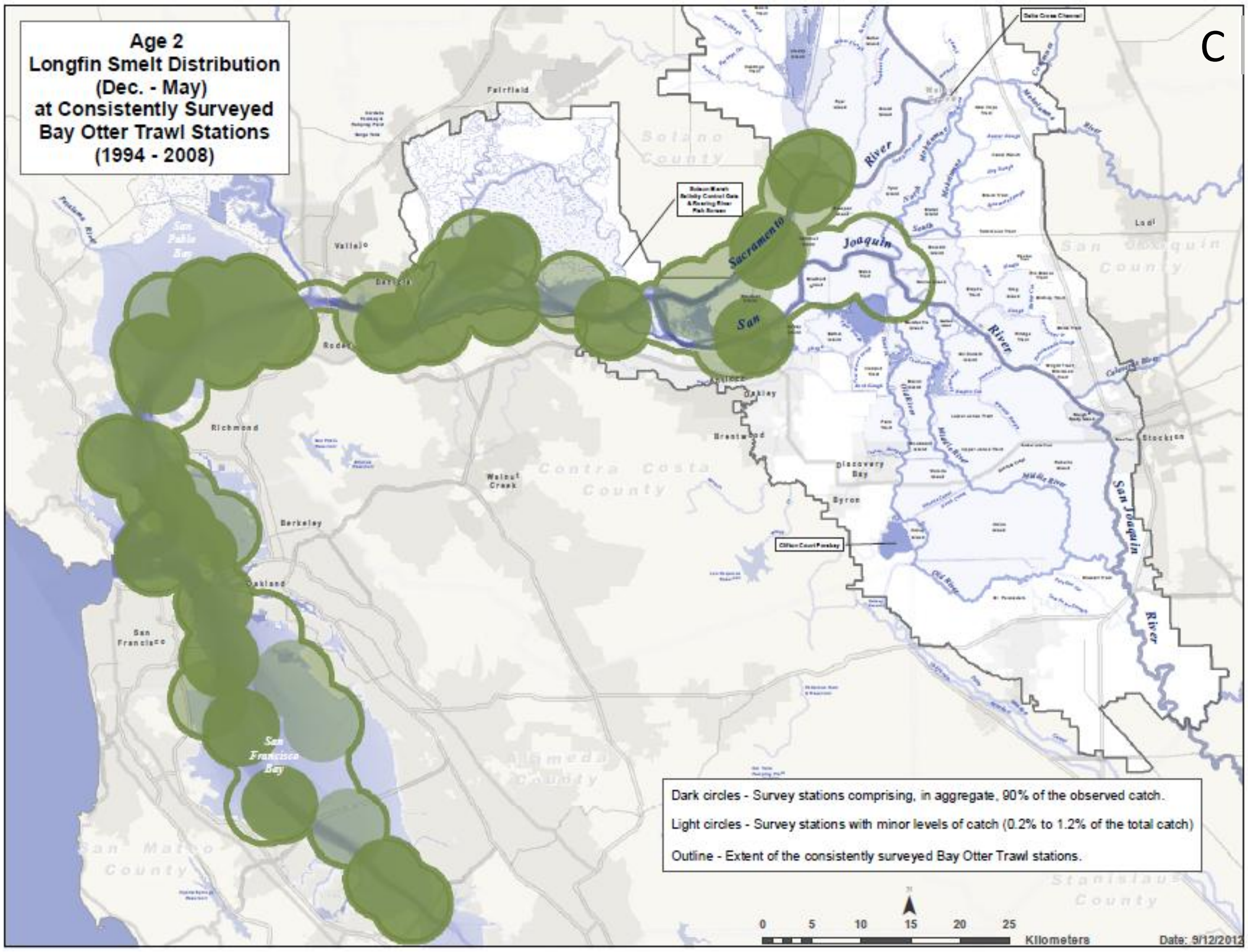

Figure 3C. Spring distribution of age-2 longfin smelt in the Bay-Delta system based on catch per unit effort. Note: the dark shaded circles represent 90% of the effort adjusted catch (major catch) and the light circles indicates the <9% effort adjusted catch (minor catch). Adult longfin smelt are found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

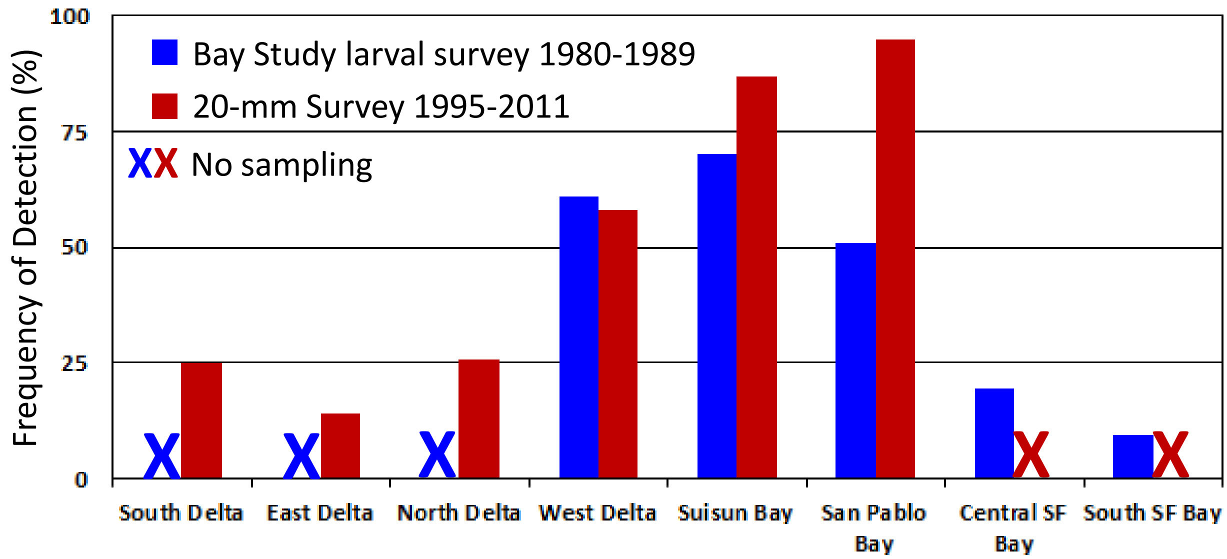

Figure 4. Percent frequency of detection of age-0 longfin smelt by region. "X" indicates no sampling and "0" indicates sampling but no longfin smelt observed. Data were from BMWT = Bay Study Midwater Trawl; BOT = Bay Study Otter Trawl; Kodiak = Spring Kodiak Trawl.

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

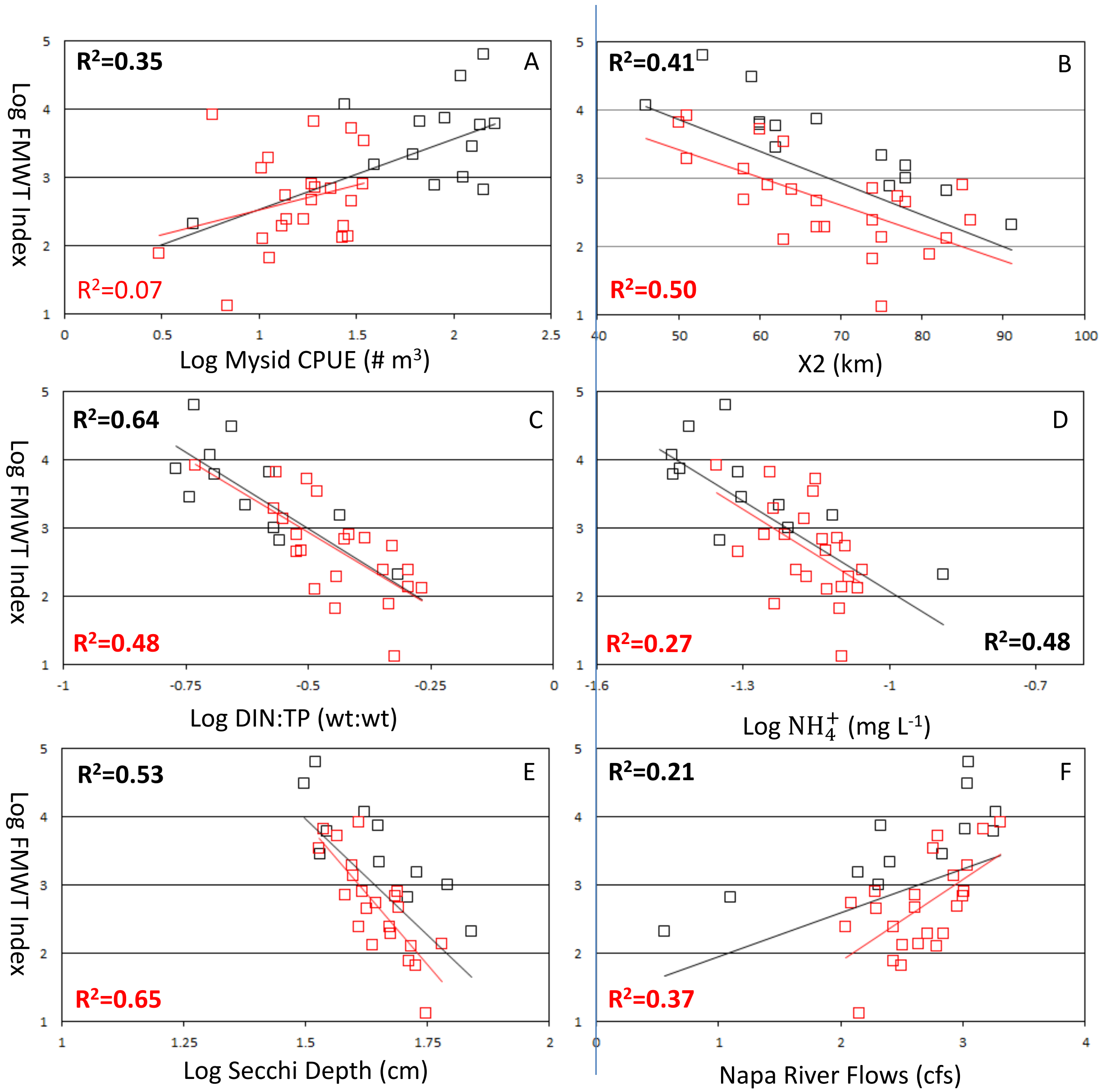

Figure 5. Relationships between various factors and longfin smelt FMWT Index. (A) Mysid CPUE (#/m³); (B) X2 (km); (C) DIN:TP (wt:wt); (D) NH_4^+ (mg L-1); (E) Secchi Depth (cm); (F) Average Napa River flows Jan-Mar (cfs). Except for X2, all values are log values. Black boxes 1975-1988; red boxes 1988-2011 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≤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.

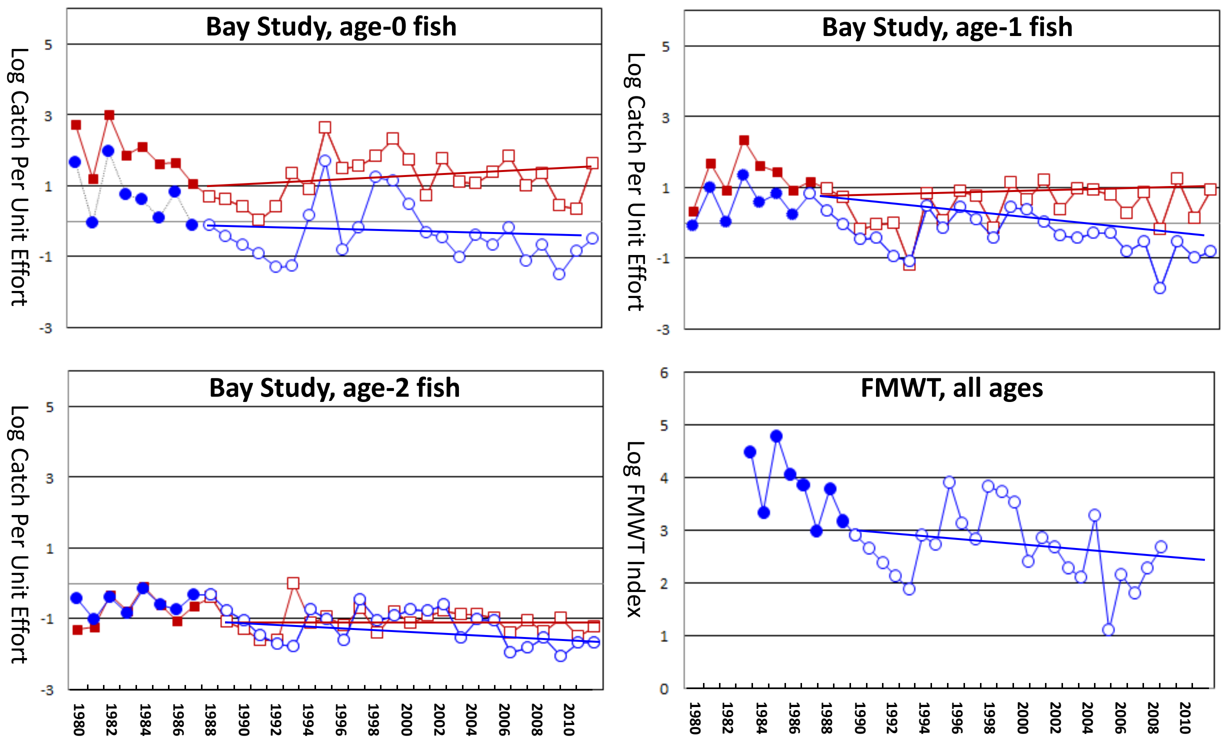

Figure 6. Bay Study trawls catch per unit effort and Fall Midwater Trawl index. Boxes are Bay Study Otter Trawl; circles are Bay Study Midwater Trawl or Fall Midwater Trawl (D). Filled symbols are 1980-1987; open symbols are 1988-2011. Trend lines are for 1988-2011. All midwater trawls show declining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

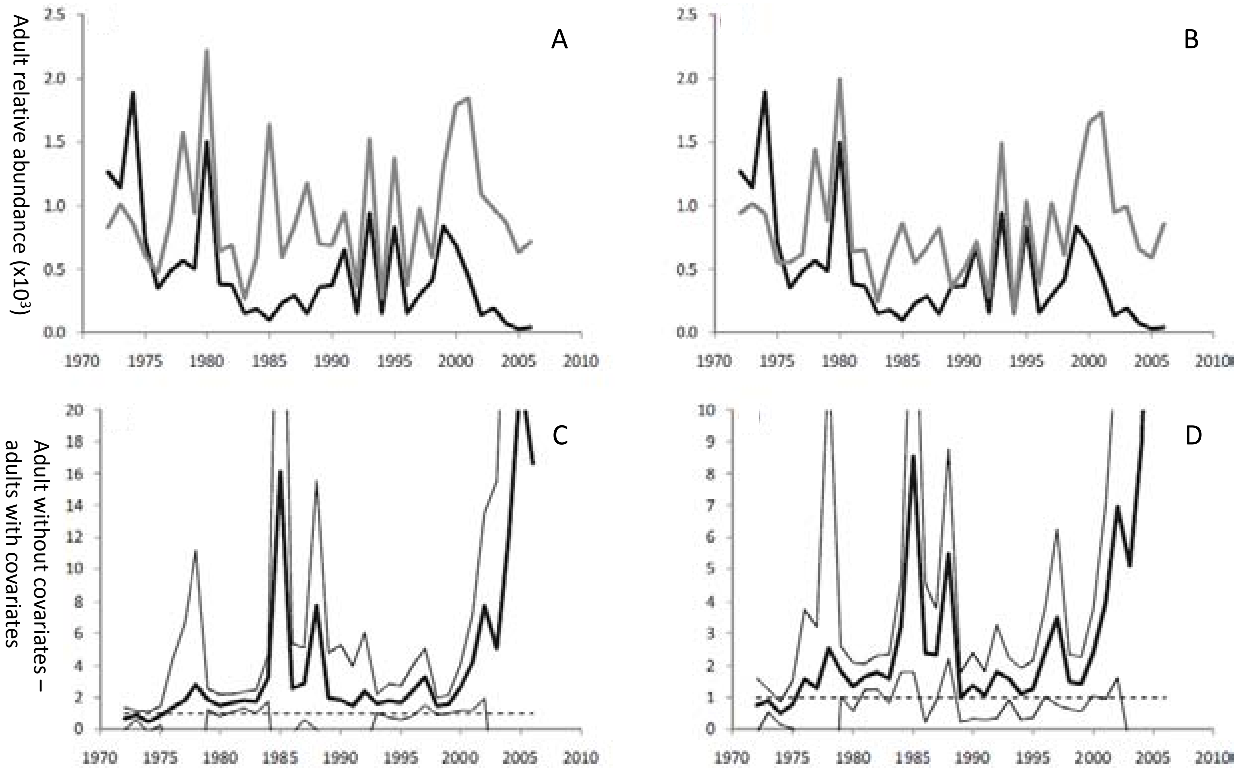

Figure 7. Estimates of abundance with and without covariates (coefficients of the covariates set to zero) (top panels) and ratio of the two with 95% confidence intervals (bottom panels, y axis limited to show details) from the lowest AICc (left panels) model that has Ricker survival from juveniles to 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).

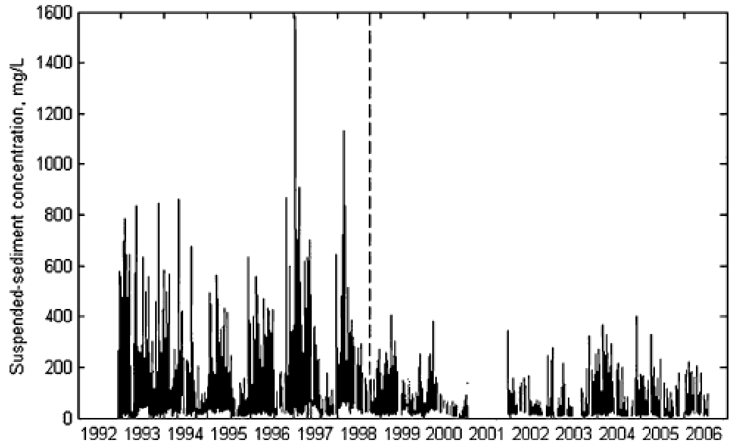

Figure 8. Suspended sediment concentration, mid-depth, Point San Pablo. The vertical dashed line indicates when the step decrease occurred. From Schoellhamer (2011). The decline in suspended sediment is obvious starting in 1999.

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).

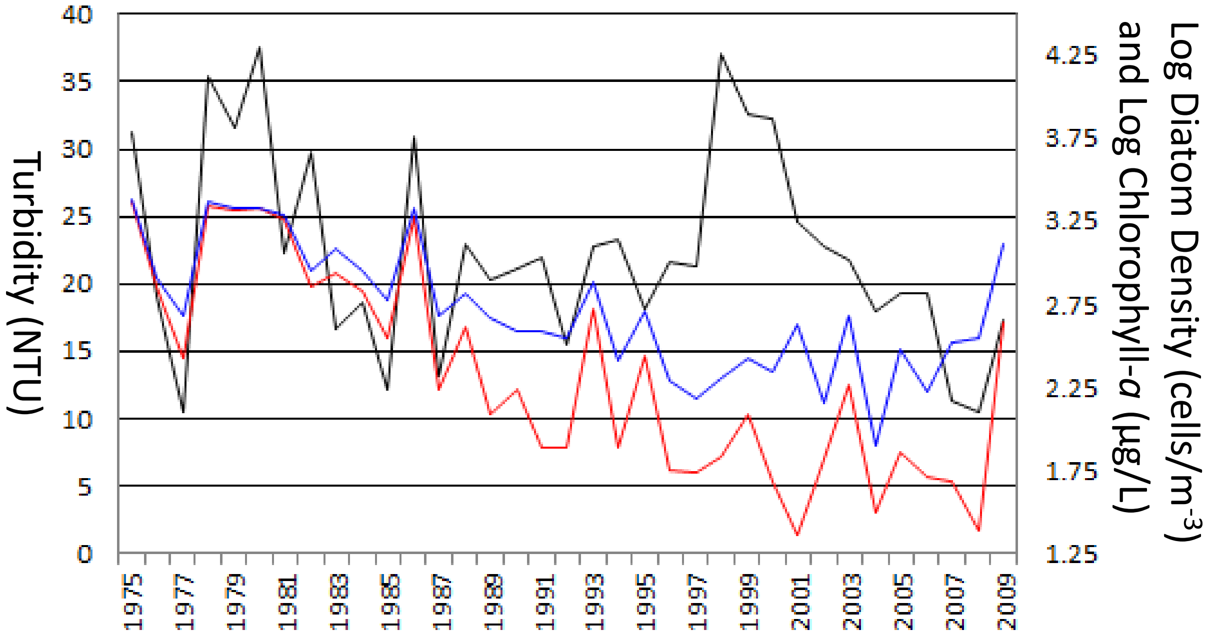

Figure 9. Historical trends in turbidity (black line), diatom density (red line), and chlorophyll-*a* (blue line) for Suisun Bay stations D4, D6, D7, D8. Turbidity and both diatom density and chlorophyll-*a* tracked fairly well until 1988. The pattern has become more divergent since then.

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.

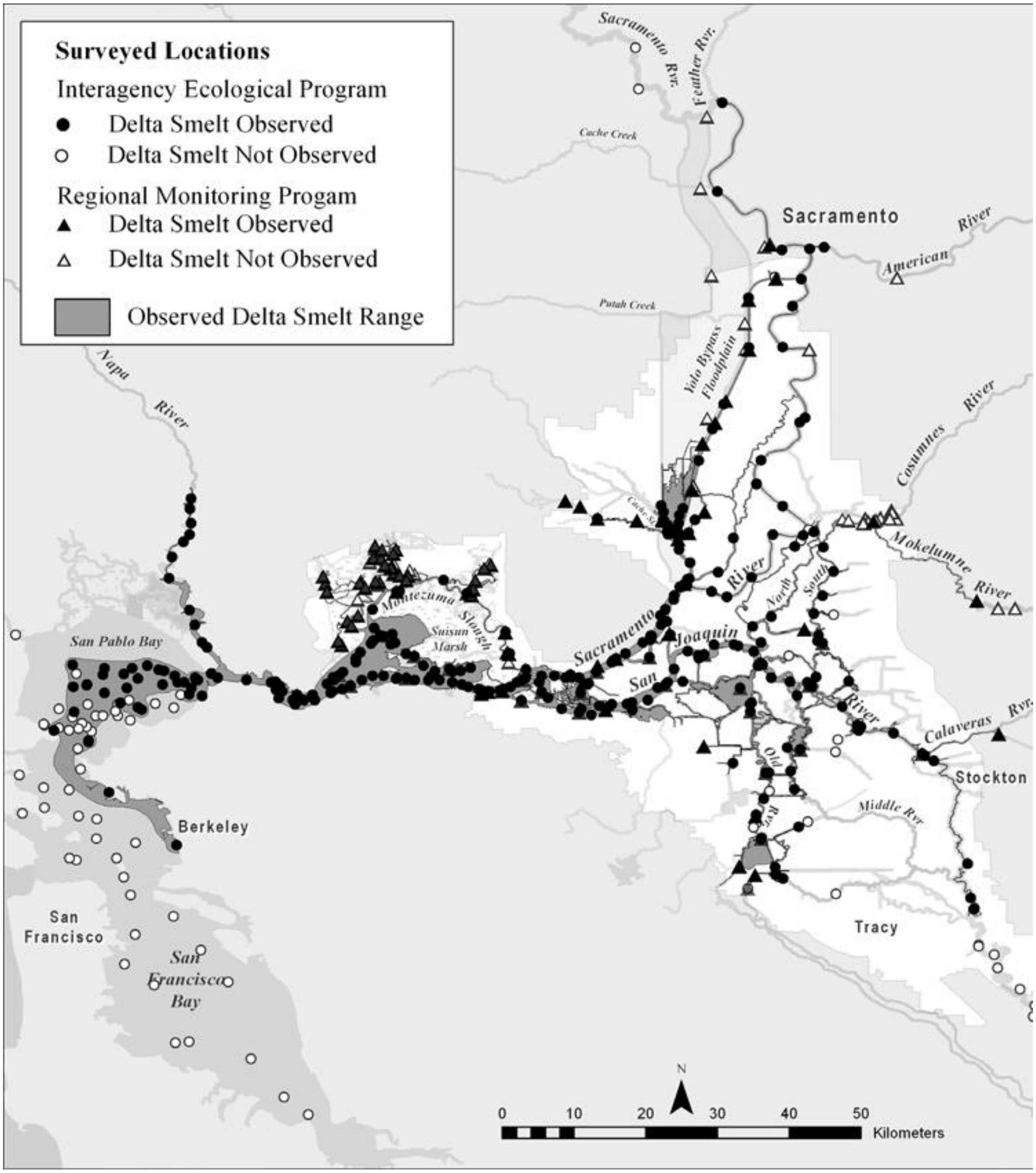

Figure 10. Distribution of delta smelt across all regular fish monitoring surveys. From Merz et al. (2011), based on presence/absence of delta smelt. In all surveys, delta smelt are found across a broad range of the estuary.

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.

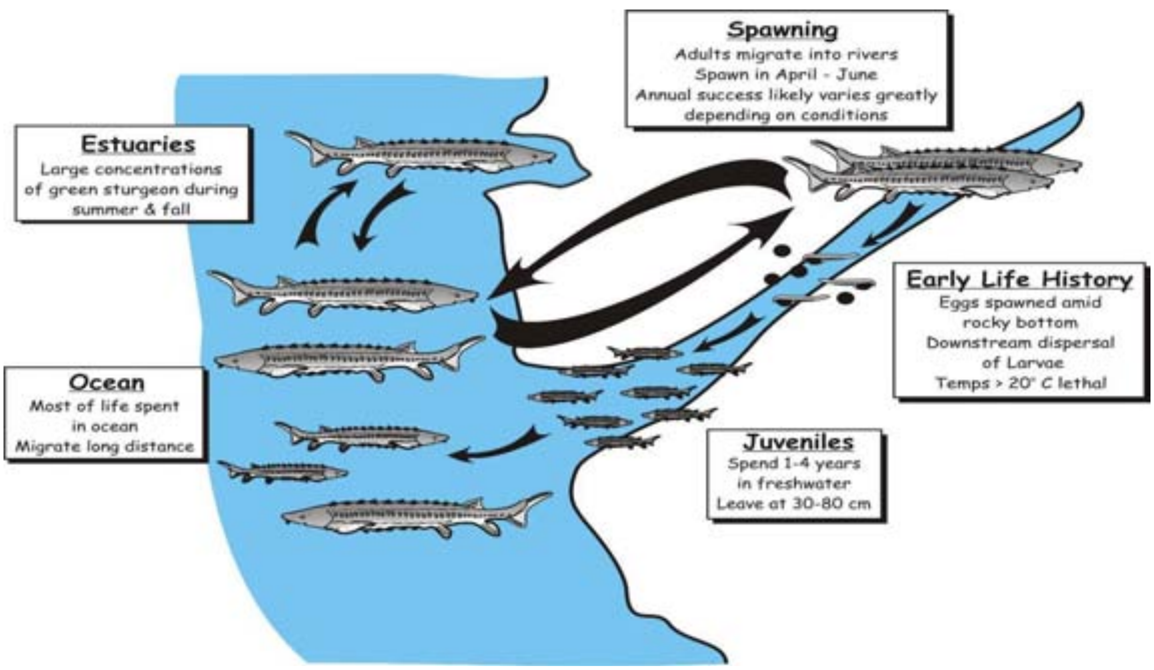


Figure 11. The green sturgeon life cycle. From Beamesderfer et al. (2007).

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

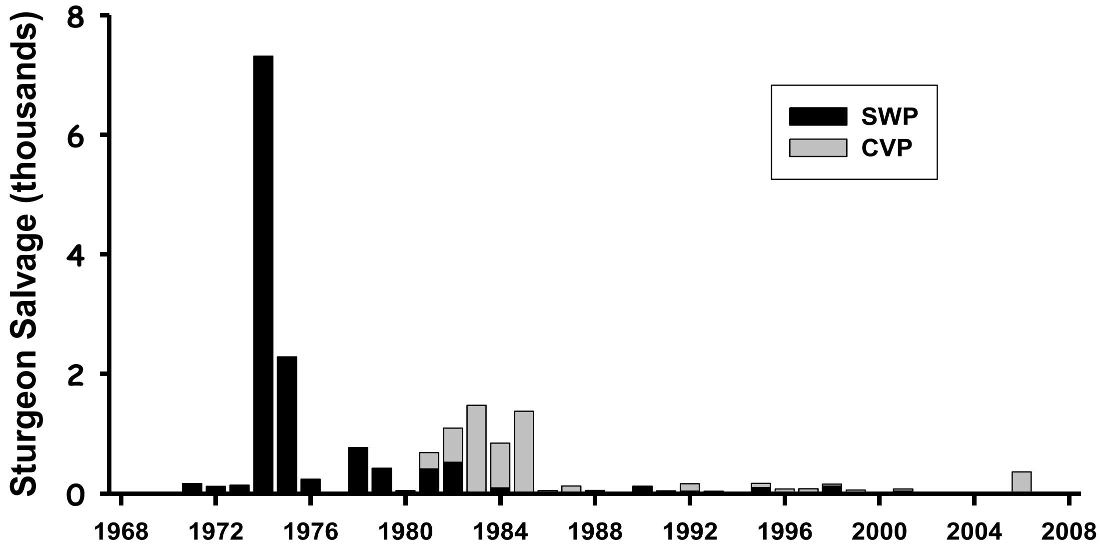
Because of their long life span and delayed maturation, sturgeon are very susceptible to overfishing. California sturgeon populations collapsed due to unregulated commercial fishing prior to 1900; numbers gradually increased over the next century. Sport fisheries for green sturgeon in California and 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



flows to

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.

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).

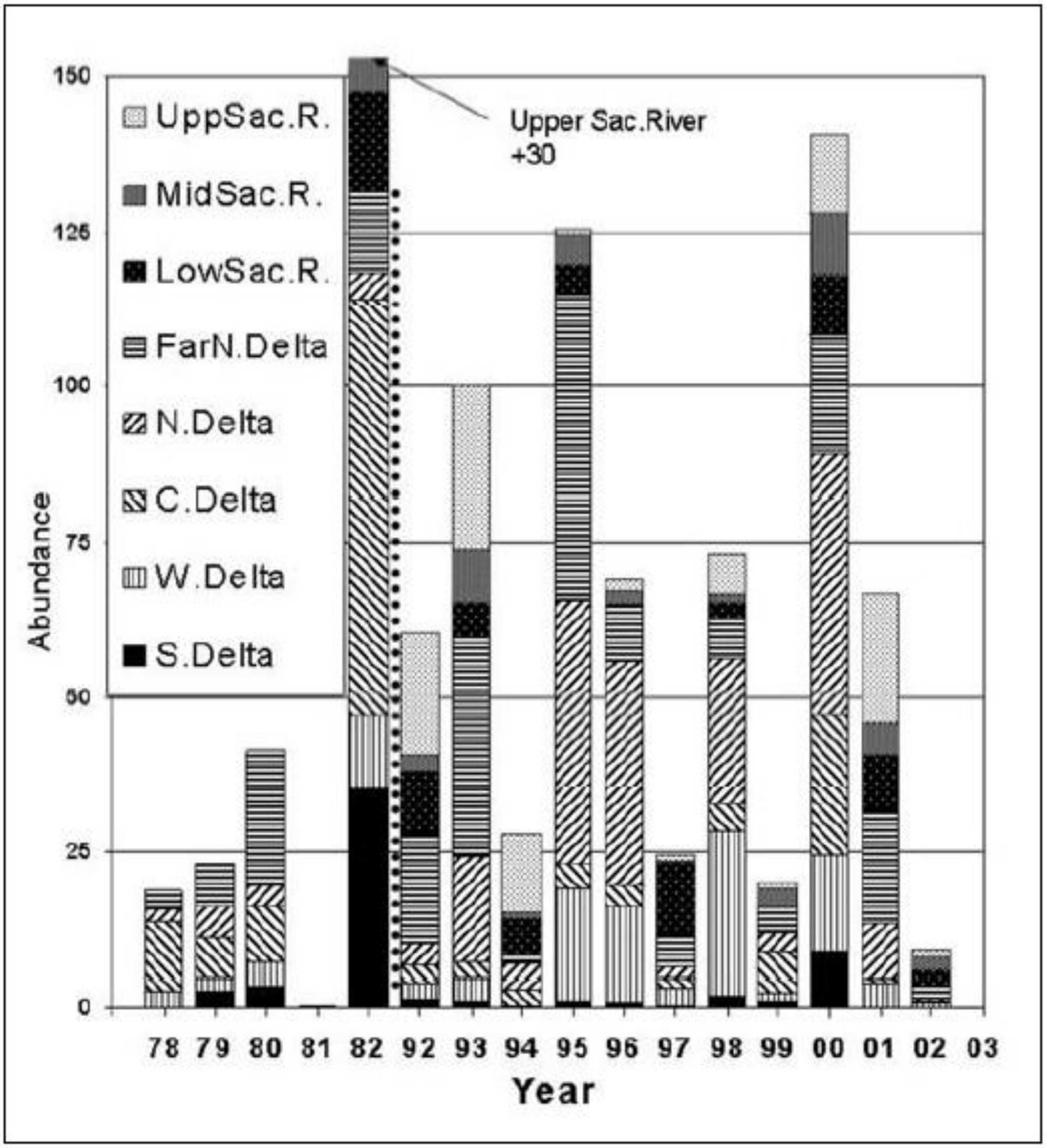


Figure 13. Age-0 splittail (>24 mm FL) abundance and distribution based on U.S. Fish and Wildlife Service beach seine survey, 1978-1982, 1992-2002. Data are mean catch per haul by region for May and June. Regions follow Sommer et al. (1997), except for those upstream of the Delta: (1) lower Sacramento 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

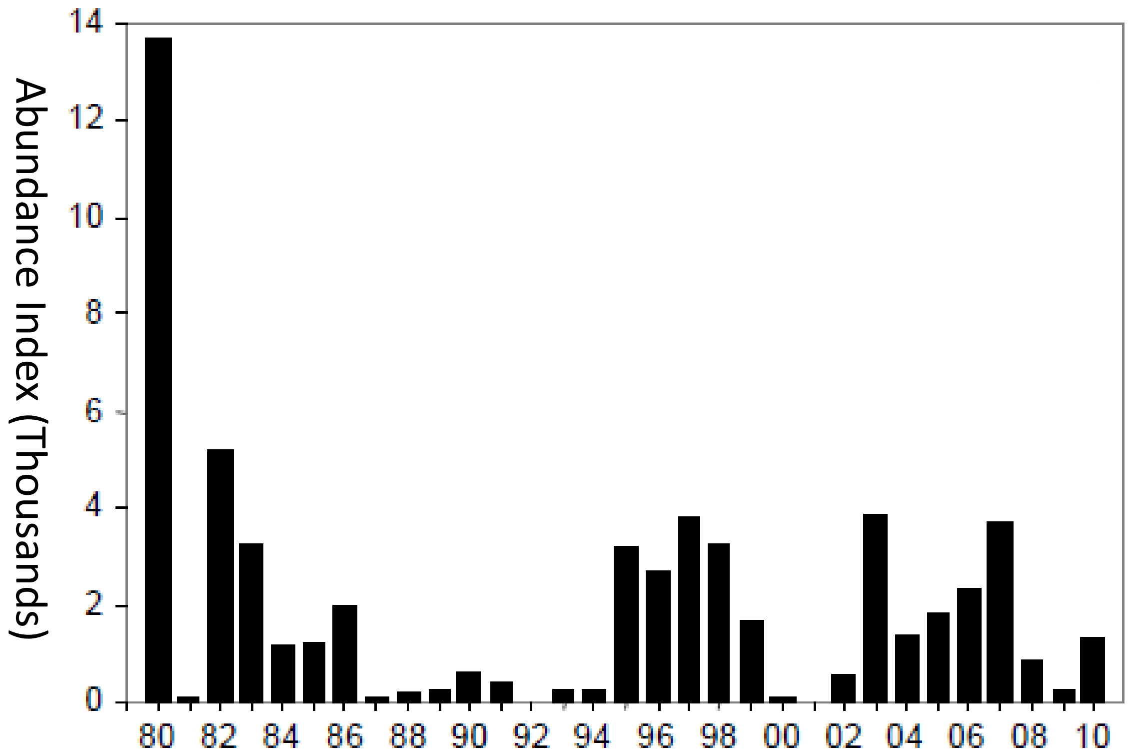


Figure 14. Annual abundance of age-0 starry flounder. Data from Bay Study Otter Trawl. Figure from *IEP Newsletter*, 2012(1), p. 24. Starry flounder appear to undergo cyclic abundances.

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.

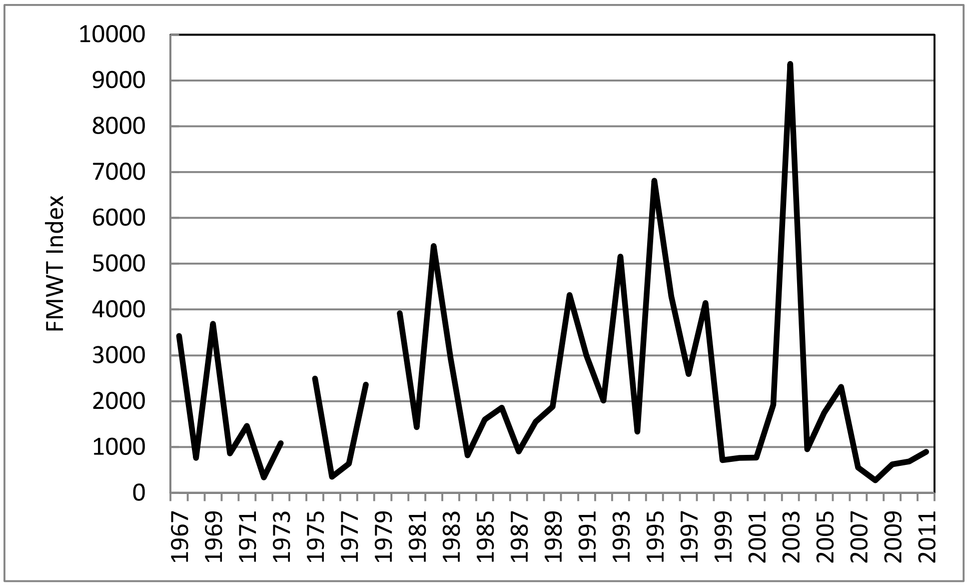


Figure 15. Annual index of American shad abundance. Data from Fall Midwater Trawl.

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

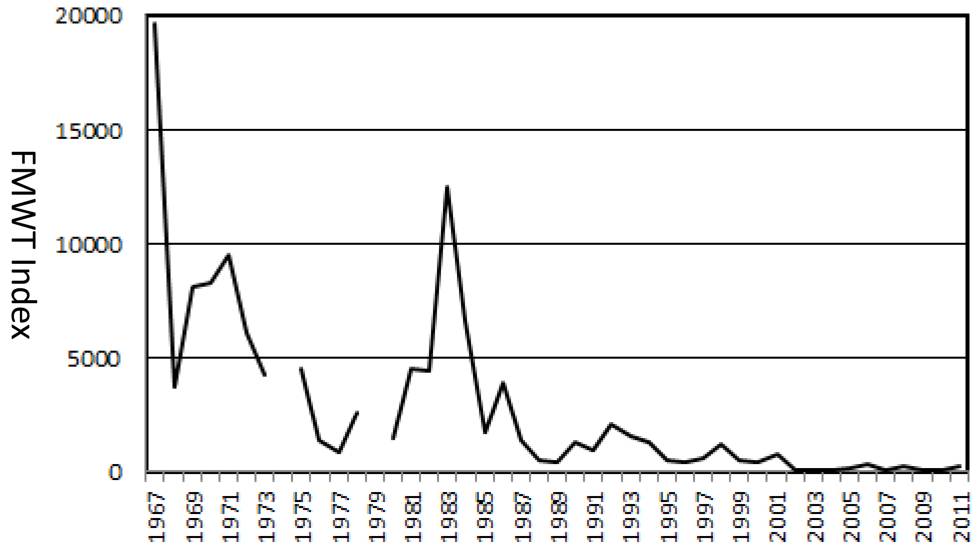


Figure 16. Fall Midwater Trawl index for striped bass.

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

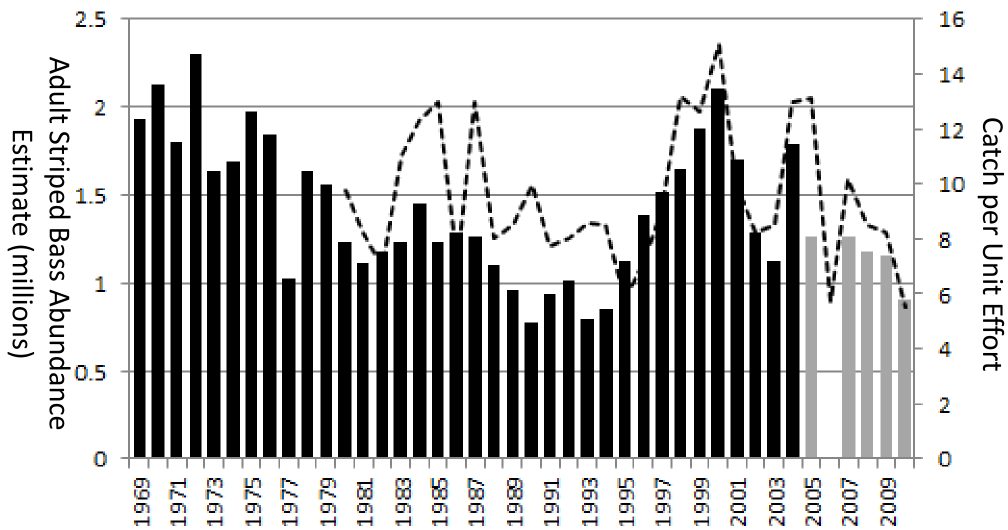


Figure 17. Population abundance estimates of adult striped bass (age-3 to age-6). Data from Loboschefsky et al. (2012) 1969-2004; 2005-2010 (gray bars) estimated using the same methods as Loboschefsky et al. 2012. Catch per unit effort (dashed line) from California Department of Fish and Game, http://nrm.dfg.ca.gov/documents/ContextDocs.aspx?cat=R3-StripedBassSt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

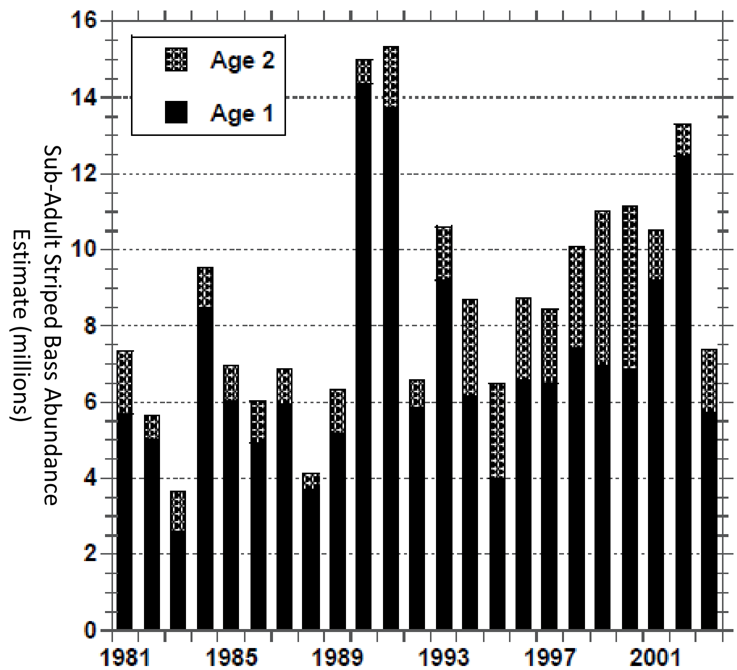


Figure 18. Population abundance estimates of sub-adult striped bass (age-1 and age-2). From Loboschefsky et al. (2012) Figure 3.

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 estuary (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).

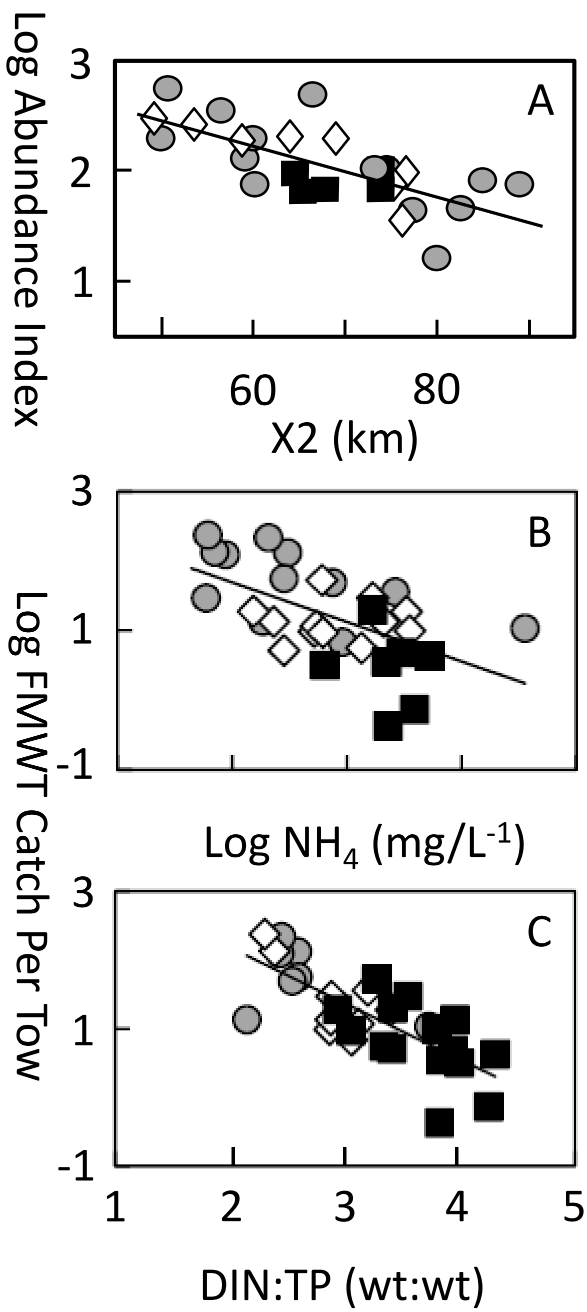


Figure 19. Change in abundance of California bay shrimp over time in relation to (A) spring X2 location, (B) ammonium, (C) nitrogen:phosphorus ratio. Abundance data is log transformed. 1975-1986 (circles); 1987-1999 (diamonds); post-1999 (squares). (A) from Kimmerer et al. (2009) Figure 3; (B) and (C)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

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.

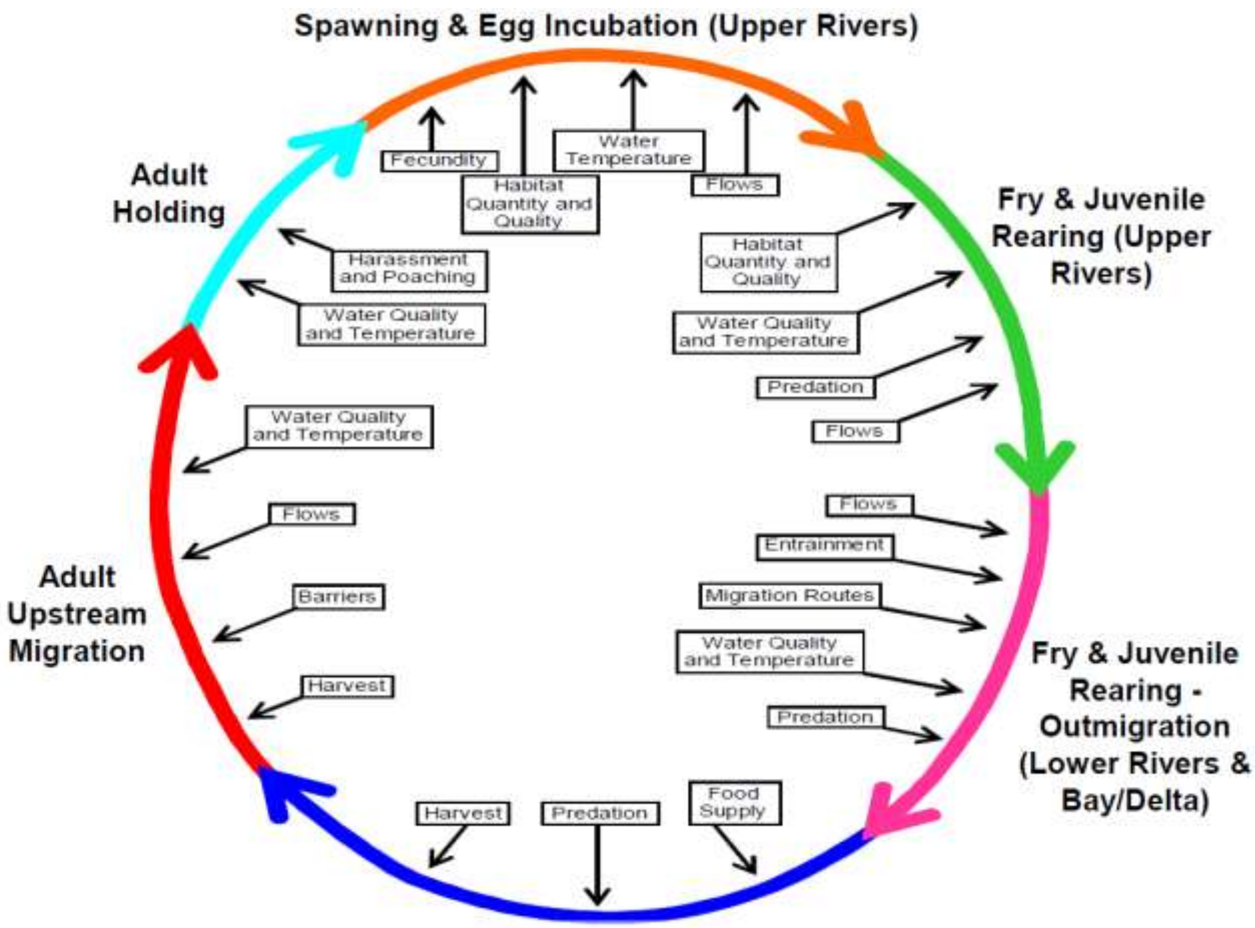

Figure 1-1. Generalized life history of Central Valley Chinook salmon and steelhead (Source: Vogel 2011). On the Sacramento River upstream habitat is defined as areas upstream of Sacramento. On the San Joaquin River upstream habitat is defined as areas upstream of Vernalis. The Delta is defined for this 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.

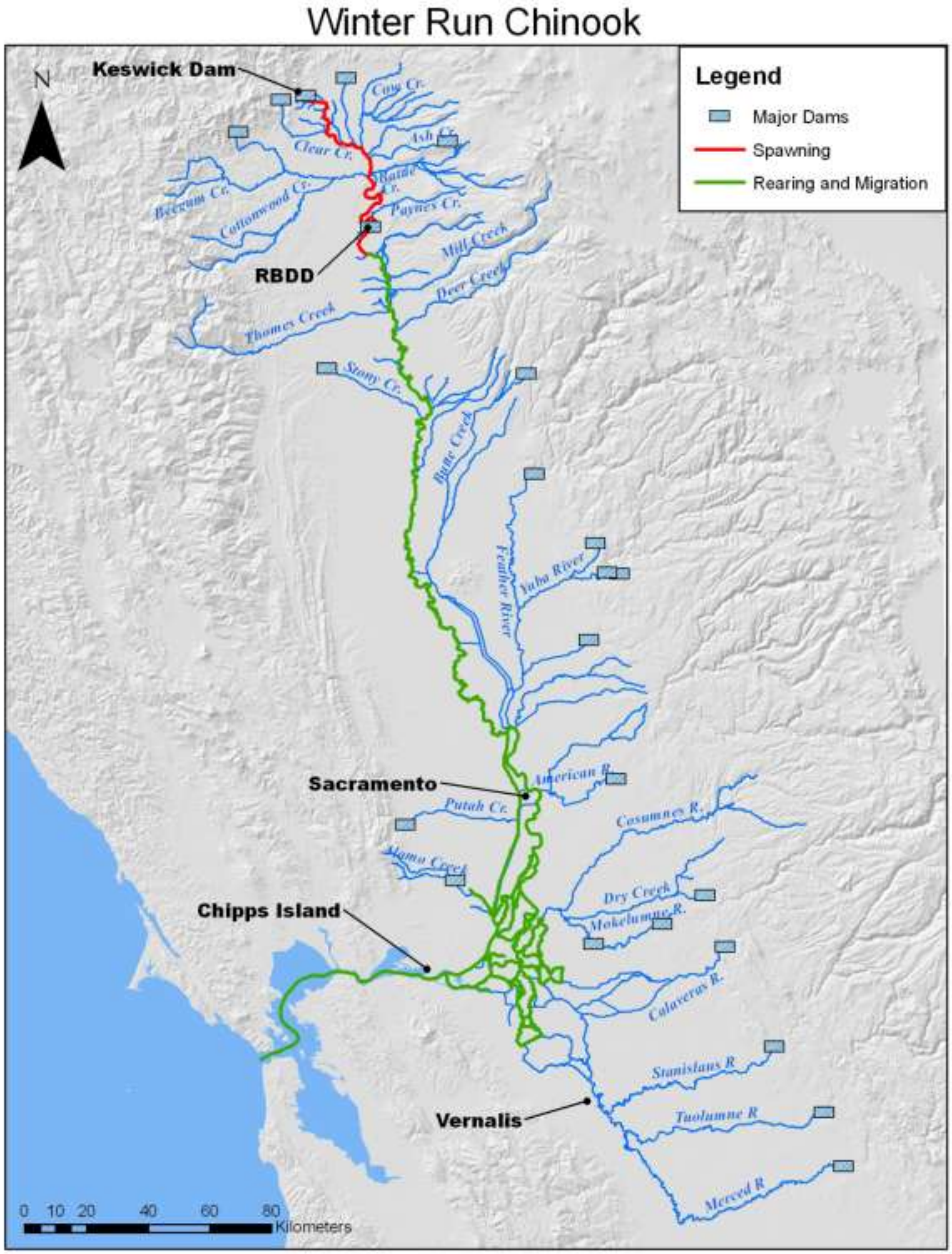

Figure 1-2. Geographic distribution of winter-run Chinook salmon in the Central Valley.

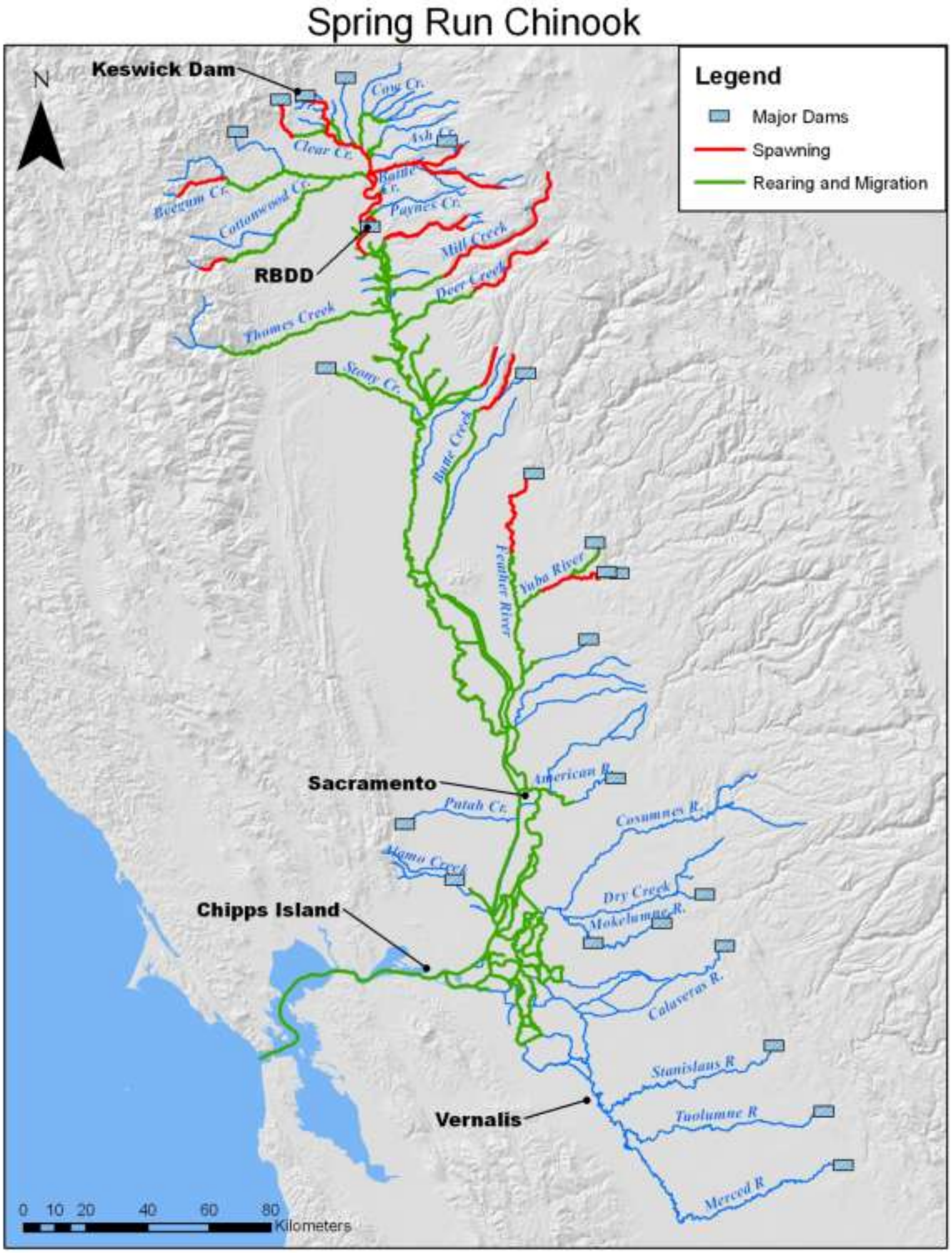

Figure 1-3. Geographic distribution of spring-run Chinook salmon in the Central Valley.

Fall-run Chinook

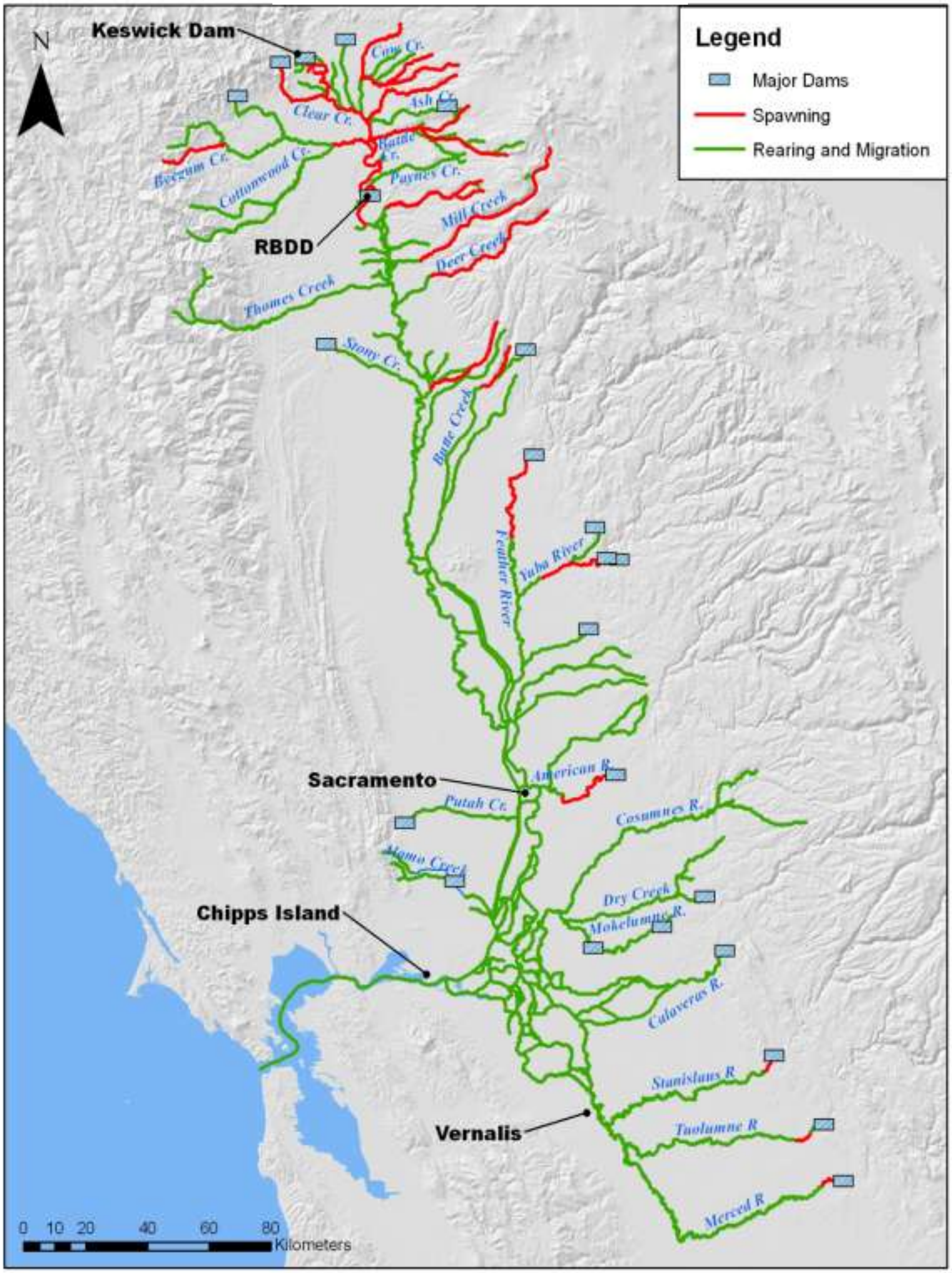

Figure 1-4. Geographic distribution of fall-run Chinook salmon in the Central Valley.

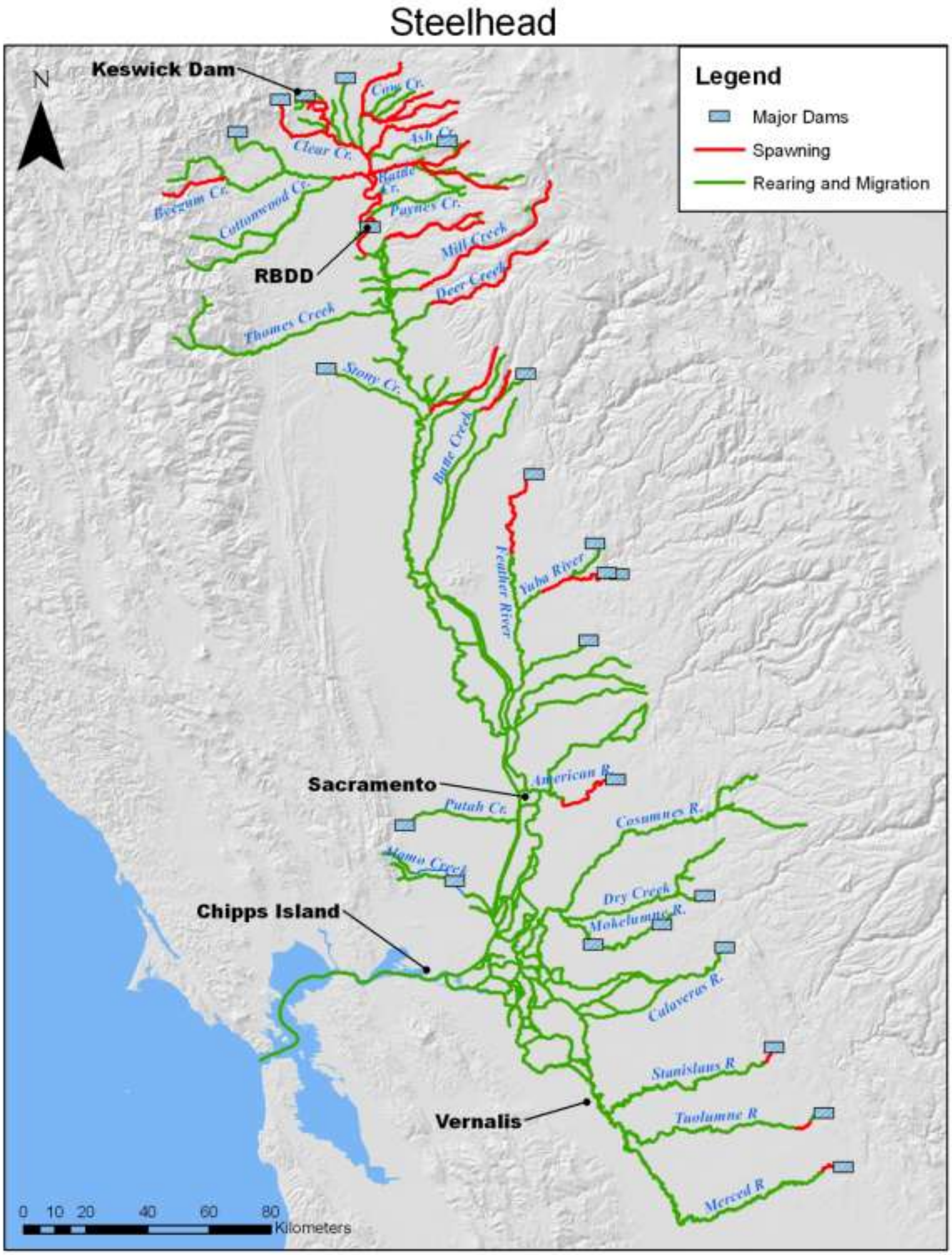

Figure 1-5. Geographic distribution of steelhead in the Central Valley.

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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).

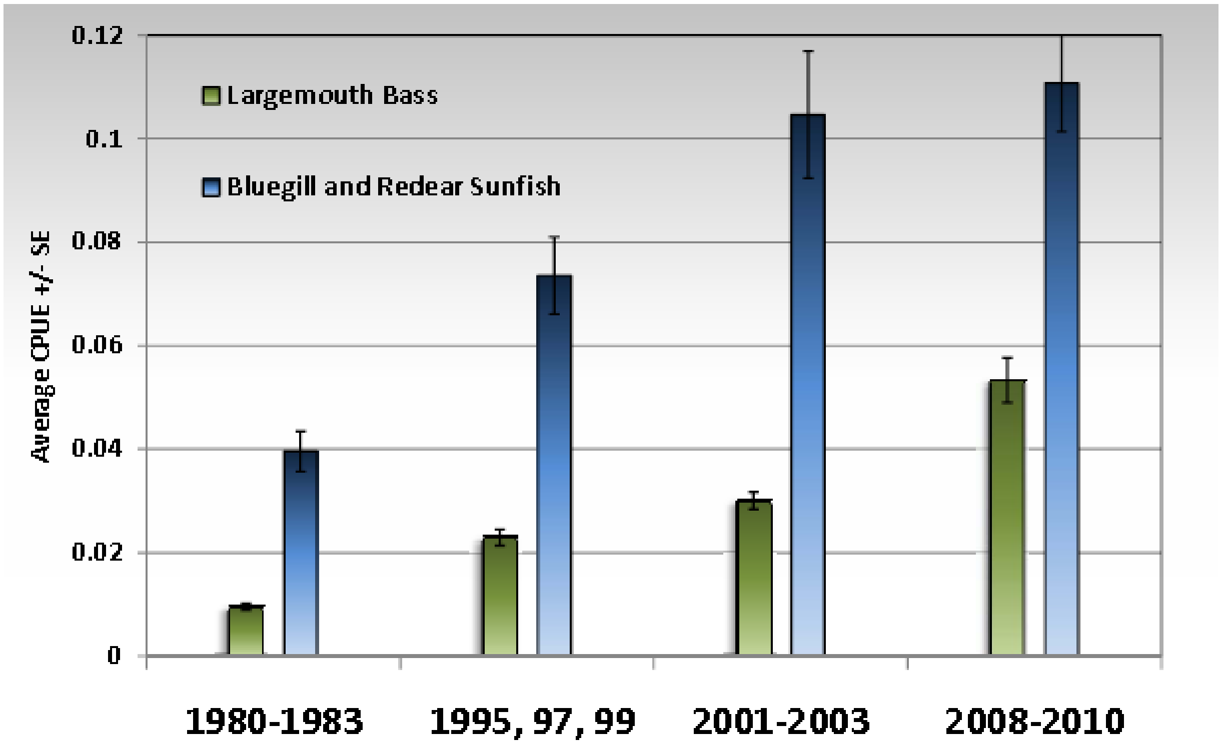

Figure 2-1. **Trends in largemouth bass and sunfish abundance in the Delta (Source: Conrad *et al.* 2010a).**

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.

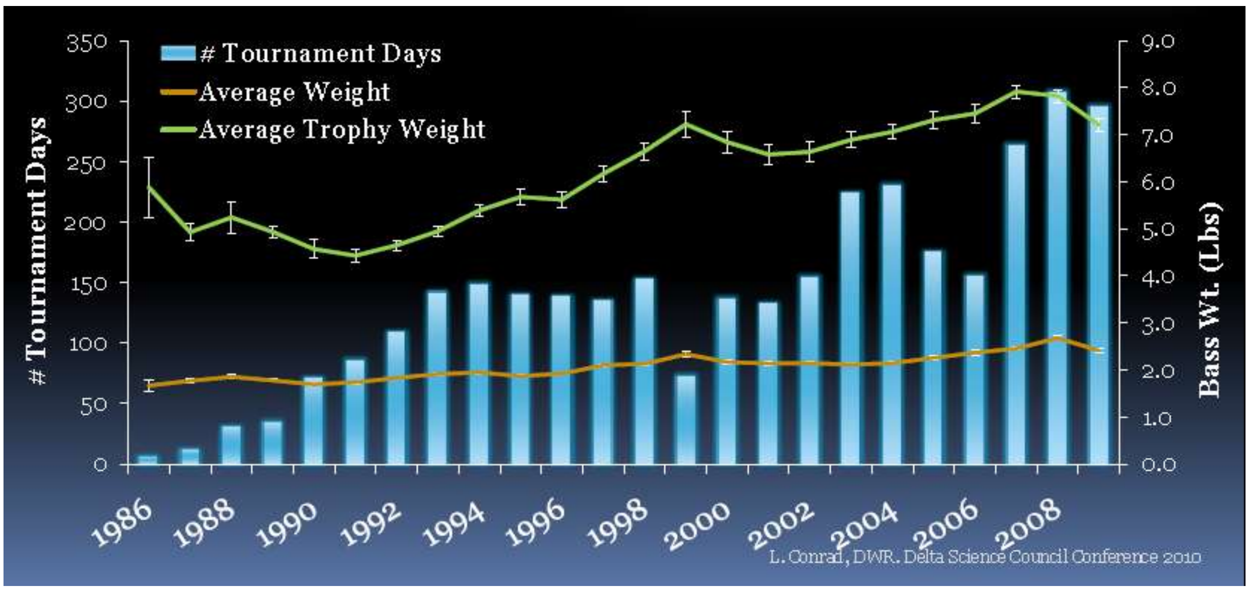

Figure 2-2. Number of largemouth bass tournament days in the Delta and trend in average weight of trophy bass (Source: Conrad *et al.* 2010b).

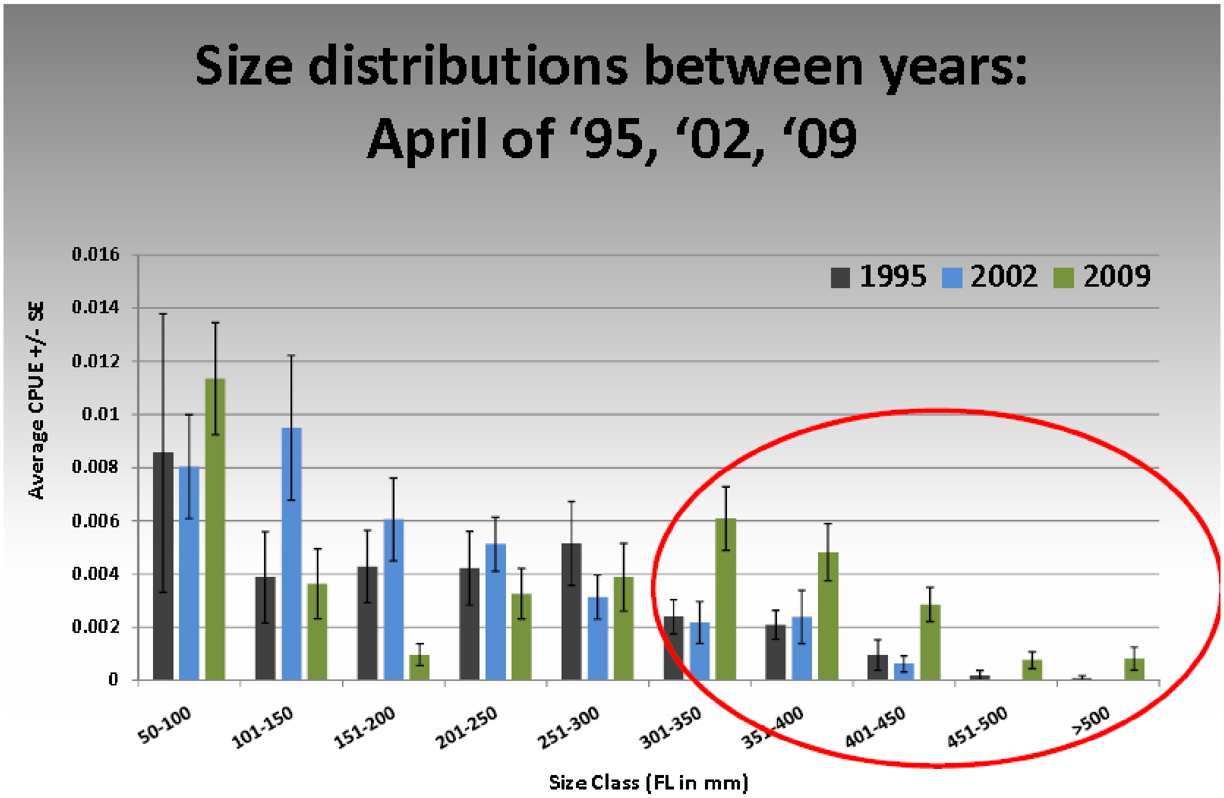

Figure 2-3. Length frequency trends in largemouth bass collected in the Delta (Source: Conrad *et al.* 2010a).

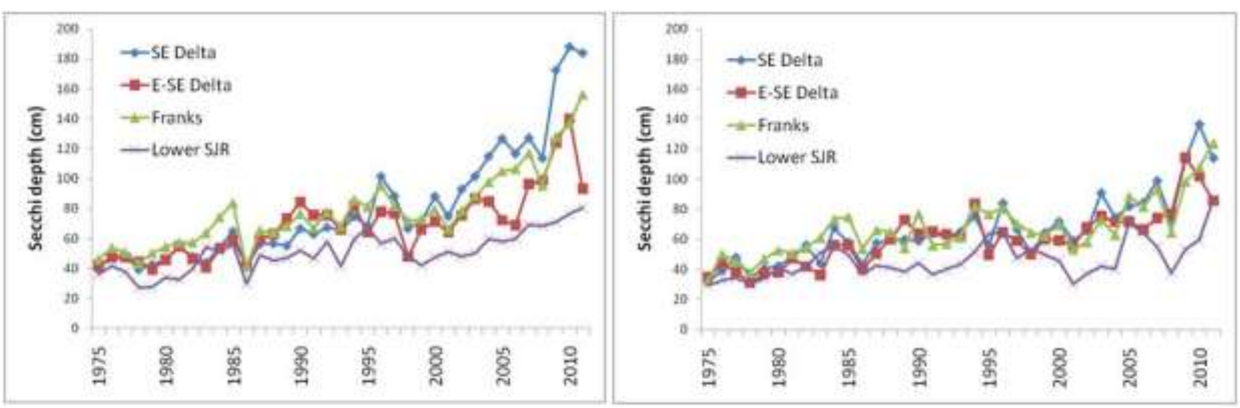

Figure 2-4. Changes in water clarity in the Delta over time as measured by Secchi depth. Left panel represents average March-June conditions and right panel represents average July – October conditions (Source: SWC/SLDMWA 2012).

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.

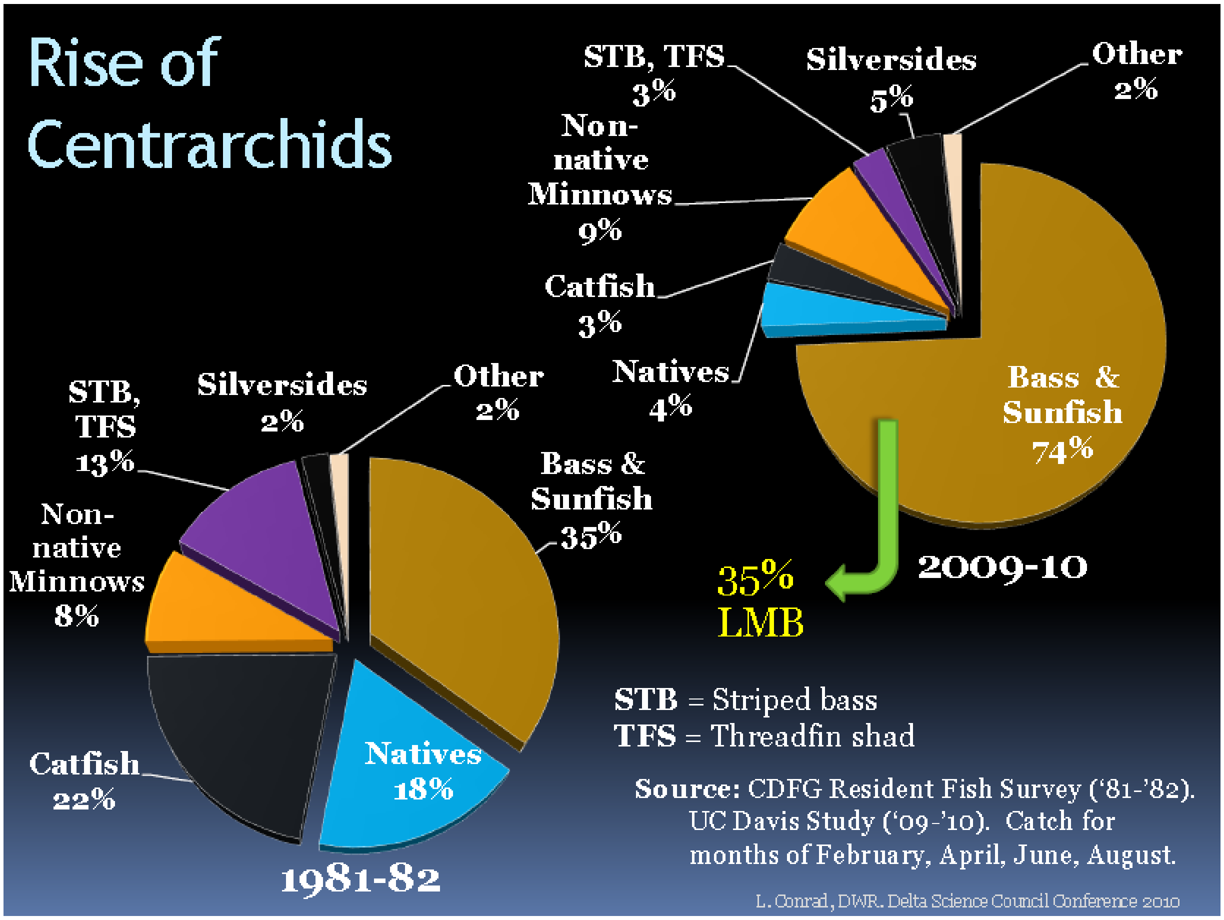

Figure 2-5. Change in fish species composition in surveys conducted in 1981-1982 and 2009-2010 (Source: Conrad *et al.* 2010 b).

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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.

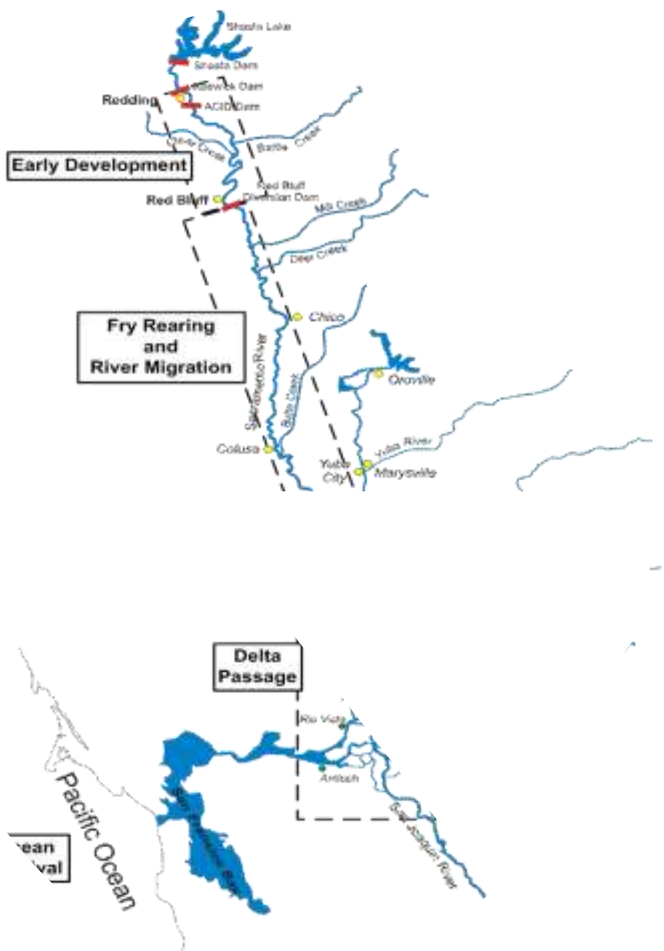

Figure 4-1. Map of the Sacramento River and the Sacramento-San Joaquin Delta, including approximate areas defined by model-stages.

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.

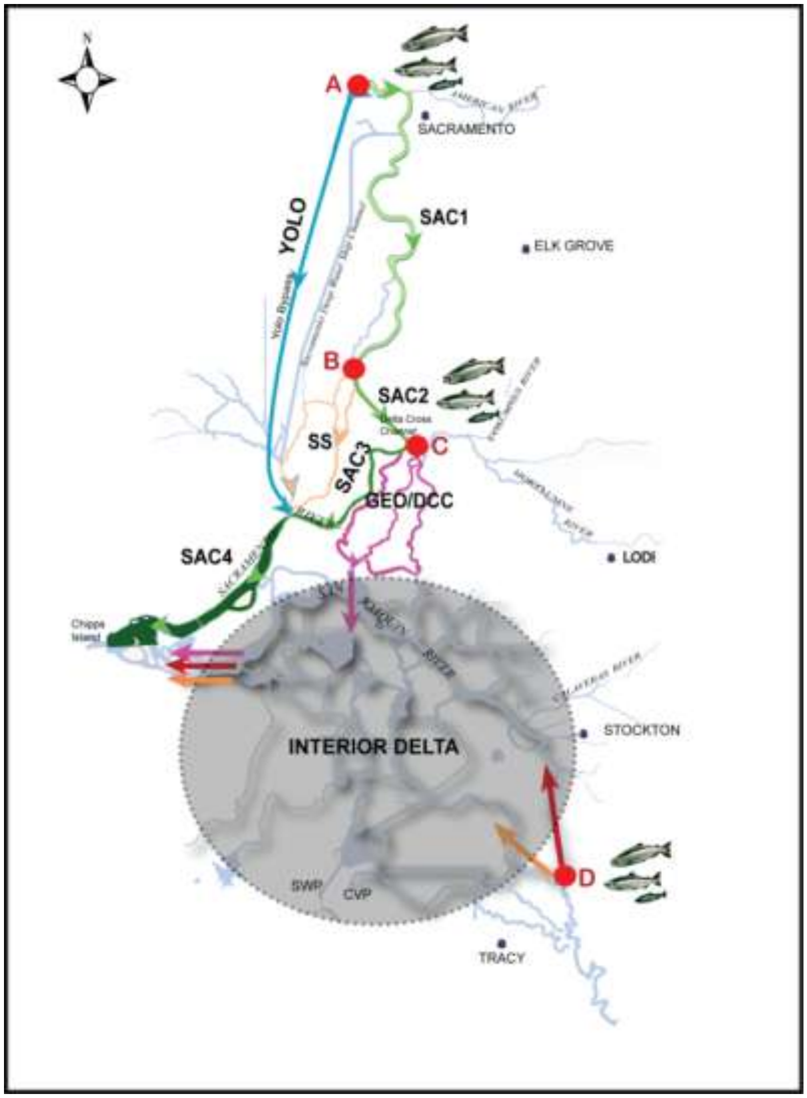

Figure 4-2. Map of the Sacramento-San Joaquin Delta showing the modeled reaches and junctions of the Delta applied in the DPM. Bold headings label modeled reaches and red circles indicate model junctions. Salmon icons indicate locations where smolts enter the Delta in the DPM.

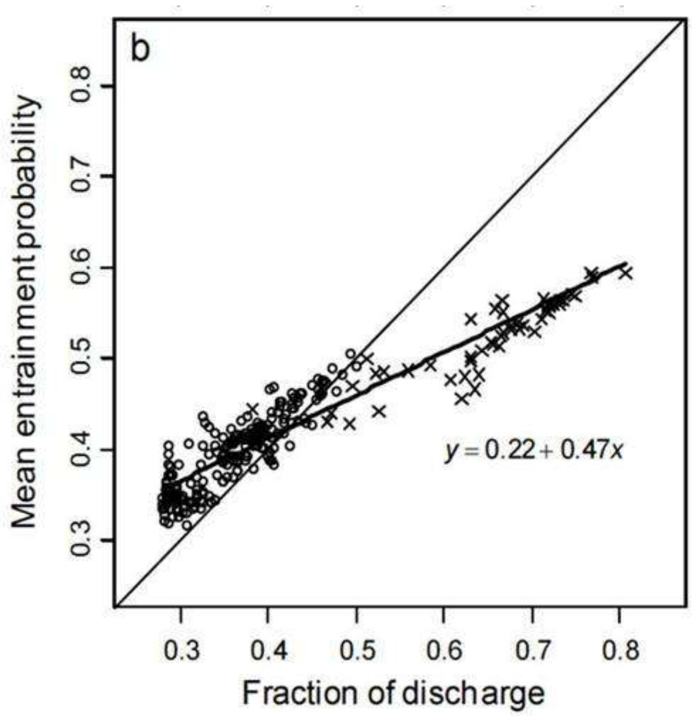

Figure 4-3. Figure from Perry (2010) depicting the mean entrainment probability (proportion of fish being diverted into reach Geo/DCC) as a function of fraction of discharge (proportion of flow entering reach Geo/DCC). In the DPM, this linear function is applied to predict the daily proportion of fish 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.

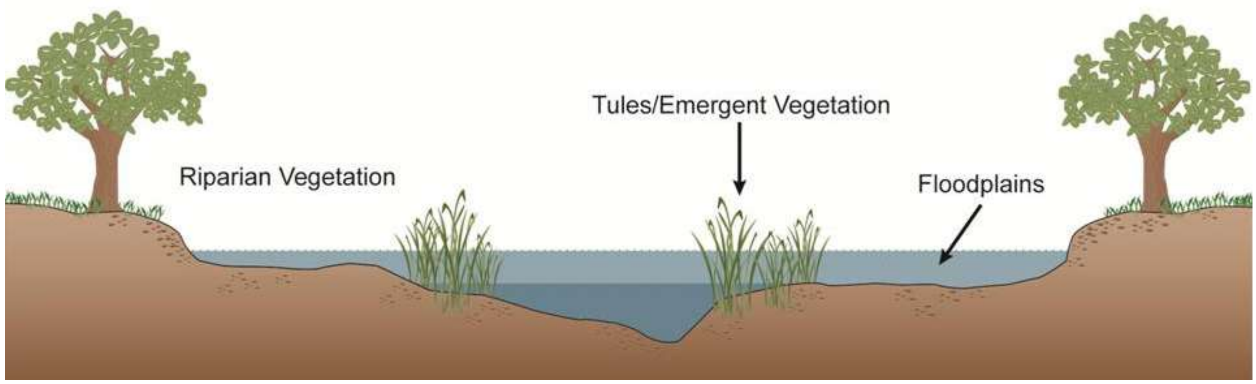

Figure 5-1. Cross section through a natural (historic) Sacramento River channel showing the change in habitat as a function of changes in river flow.

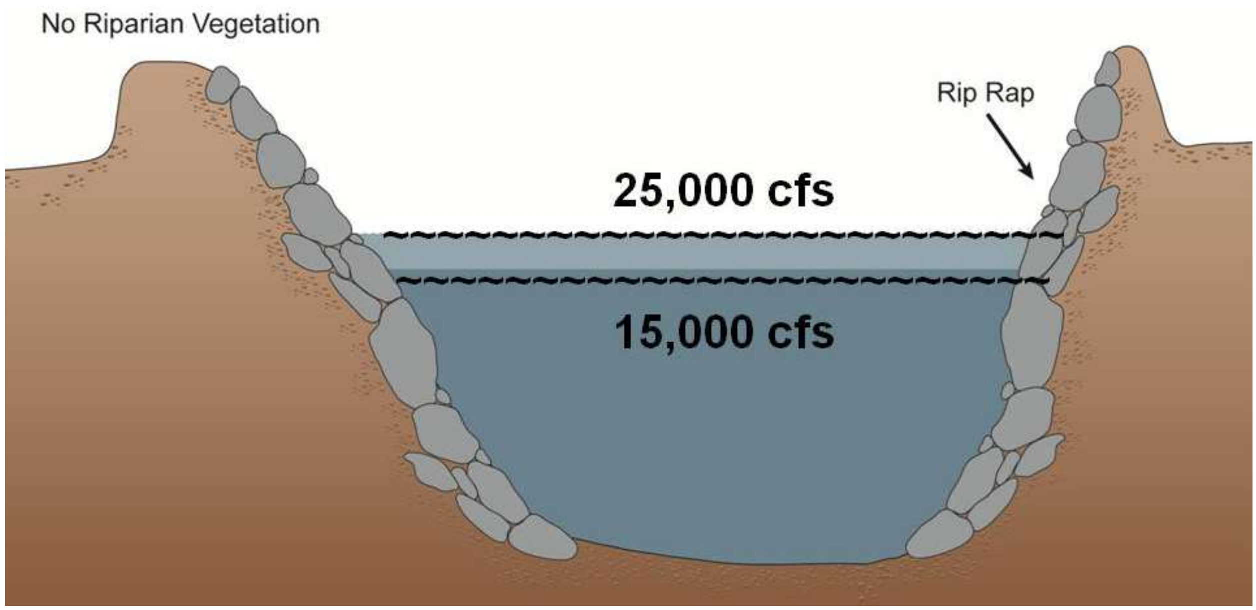

Figure 5-2. Cross section through a channelized reach of the Sacramento River showing the change in habitat as a function of changes in river flow.

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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.

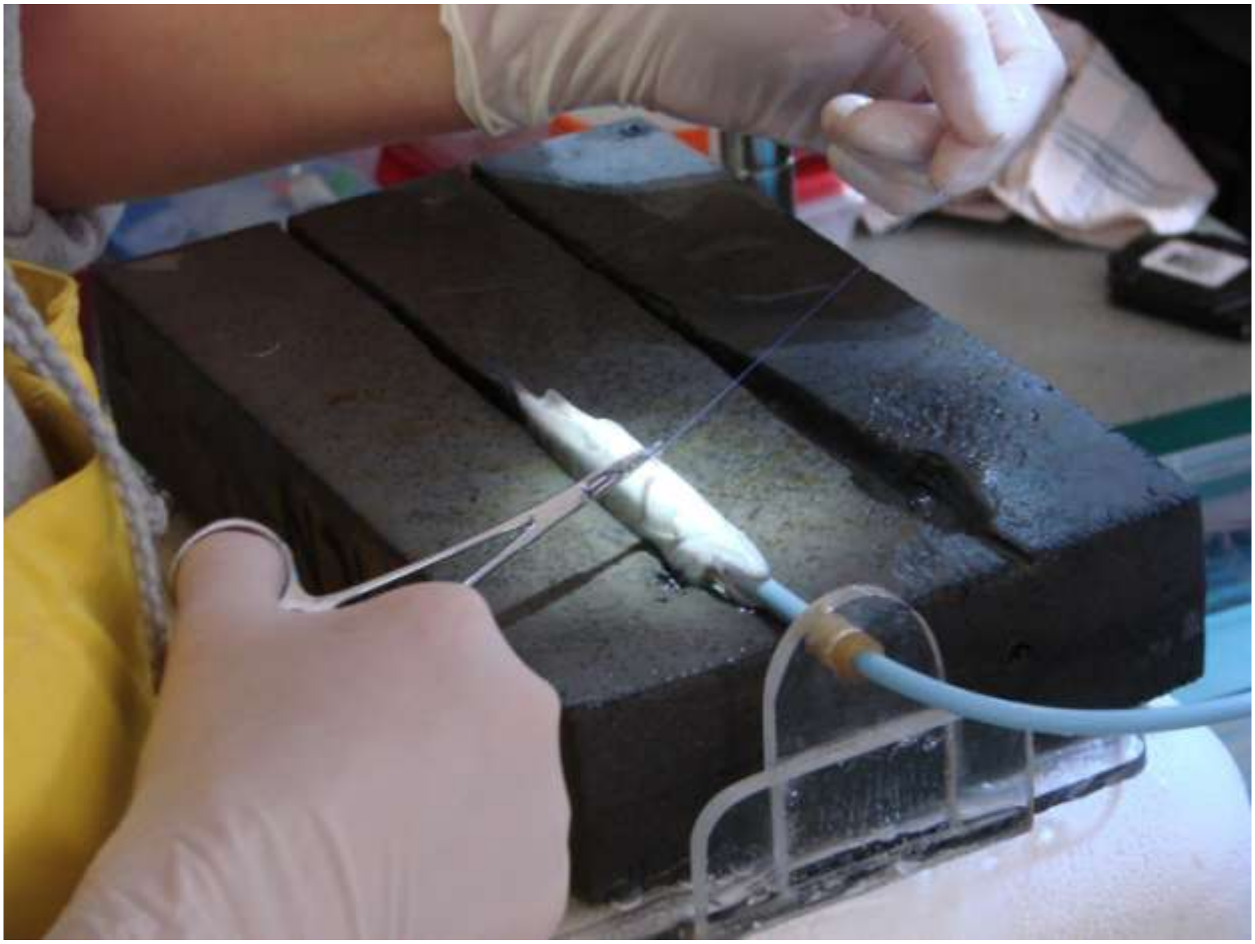

Figure 6-1. Surgically implanting an acoustic tag into a juvenile Chinook salmon.

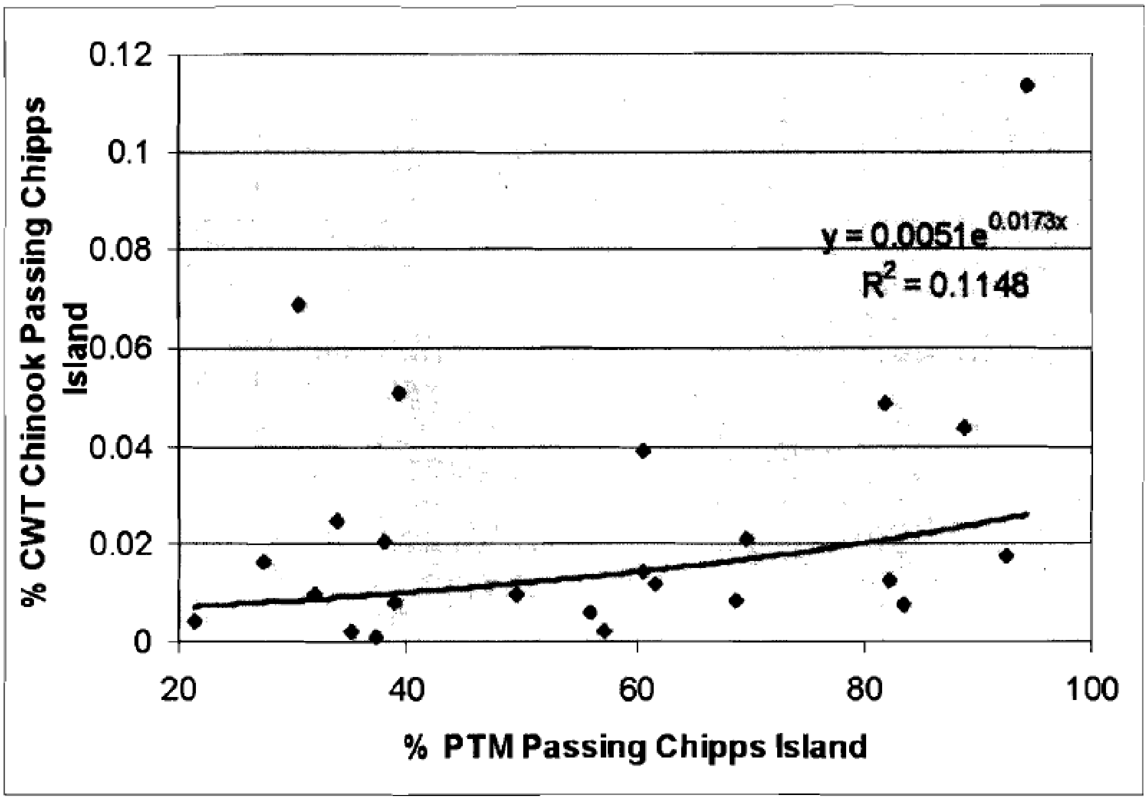

Figure 6-2. **Results of a validation test of the percentage of particles in a PTM model scenario passing Chipps Island and corresponding percentage of CWT juvenile Chinook salmon to Chipps Island (Source: USBR and DWR 2009, NMFS 2012).**

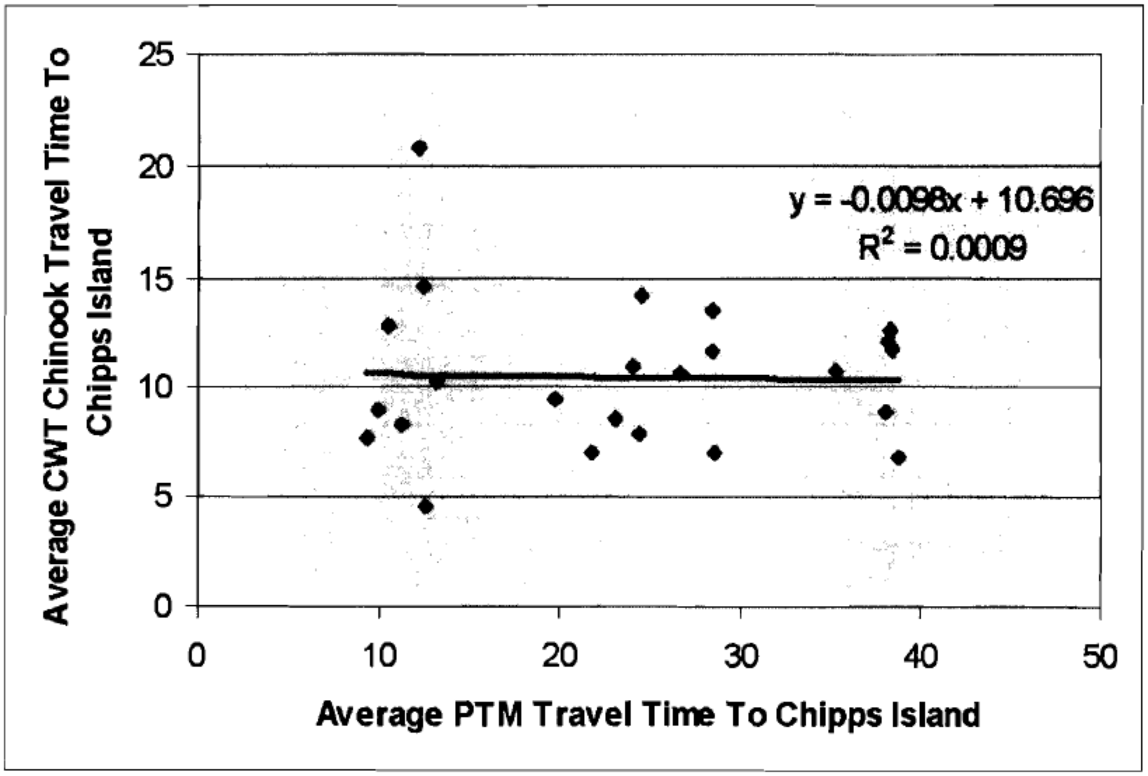

Figure 6-3. Results of a validation test of the travel time of particles in a PTM model scenario passing Chipps Island and corresponding average travel time of CWT juvenile Chinook salmon to Chipps Island (Source: USBR and DWR 2009, NMFS 2012).

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).

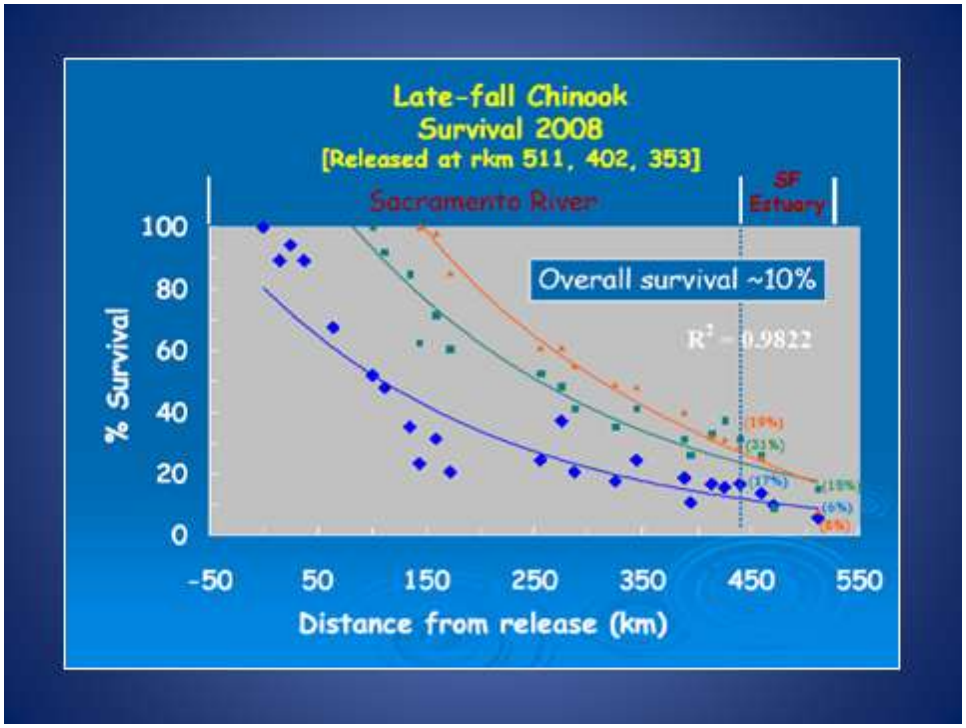

Figure 7-1. **Results of acoustic tag studies on late fall-run Chinook salmon survival during migration through the Sacramento River, Delta, and estuary (Source: MacFarland *et al.* 2008)**

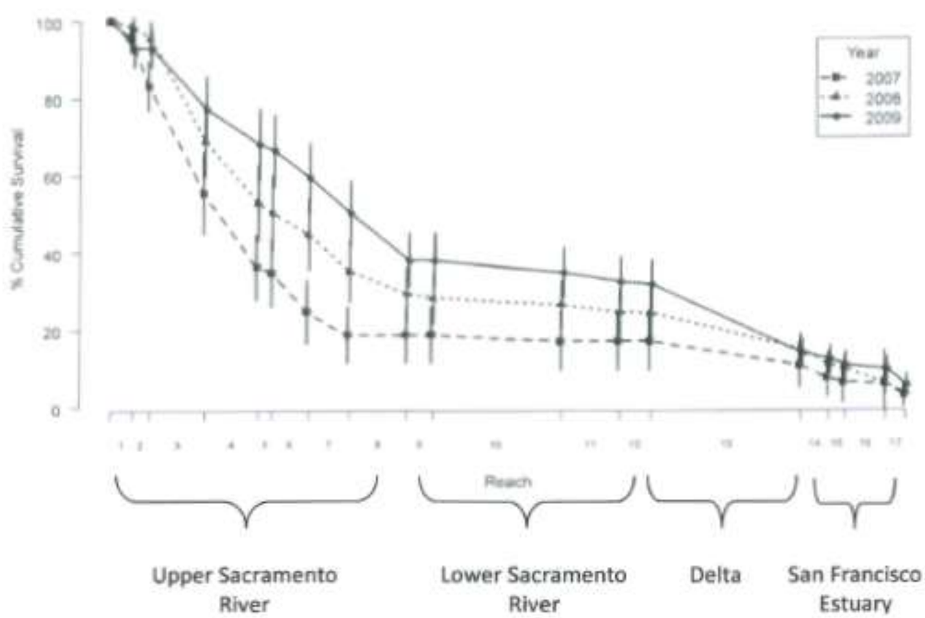

Figure 7-2. **Reach-specific survival estimates for late fall-run Chinook salmon juveniles migrating downstream in the Sacramento river, Delta, and estuary over 3 years (Source: Michel 2010).**

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).

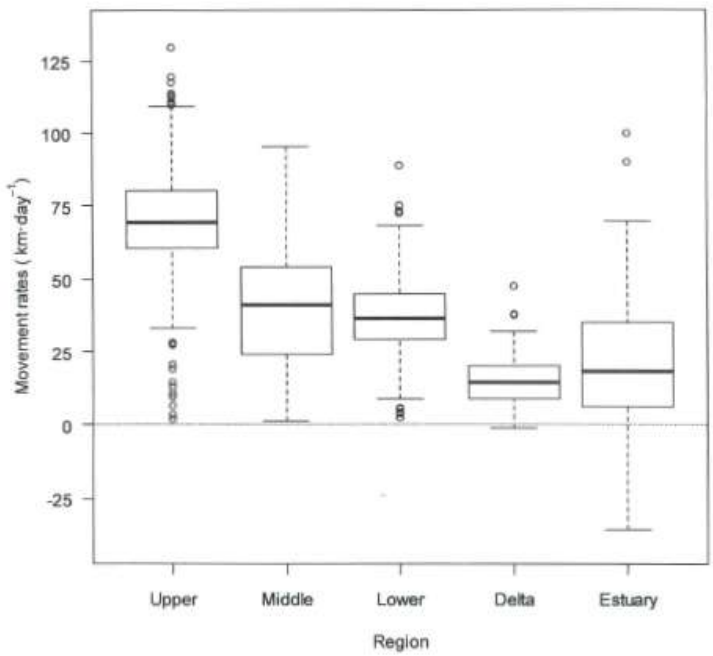

Figure 7-3. Reach specific migration rates for acoustically tagged late fall-run Chinook salmon in the Sacramento River, Delta, and estuary (Source: Michel 2010).

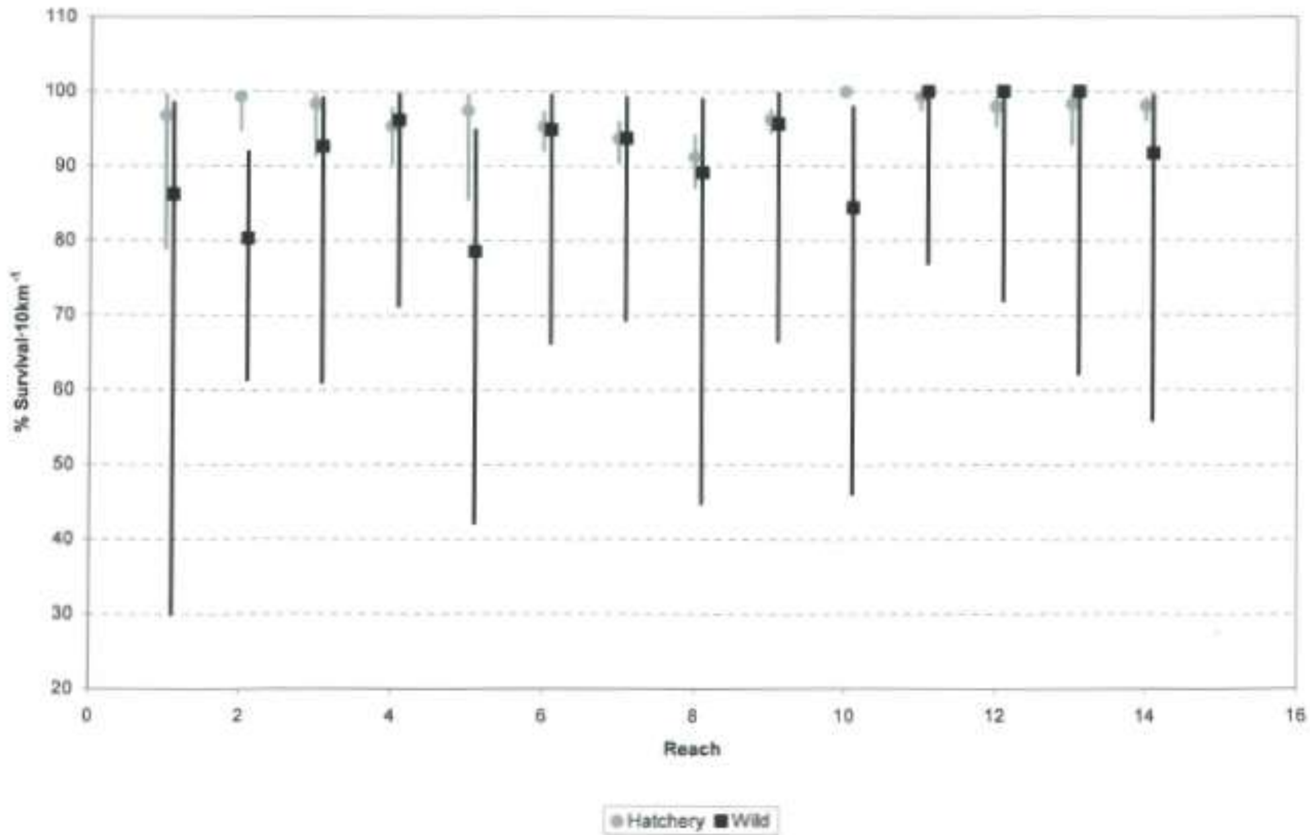

Figure 7-4. Results of a preliminary comparison of survival rates for wild and hatchery origin juvenile Chinook salmon in the Sacramento River, Delta, and estuary (Source: Michel 2010).

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.

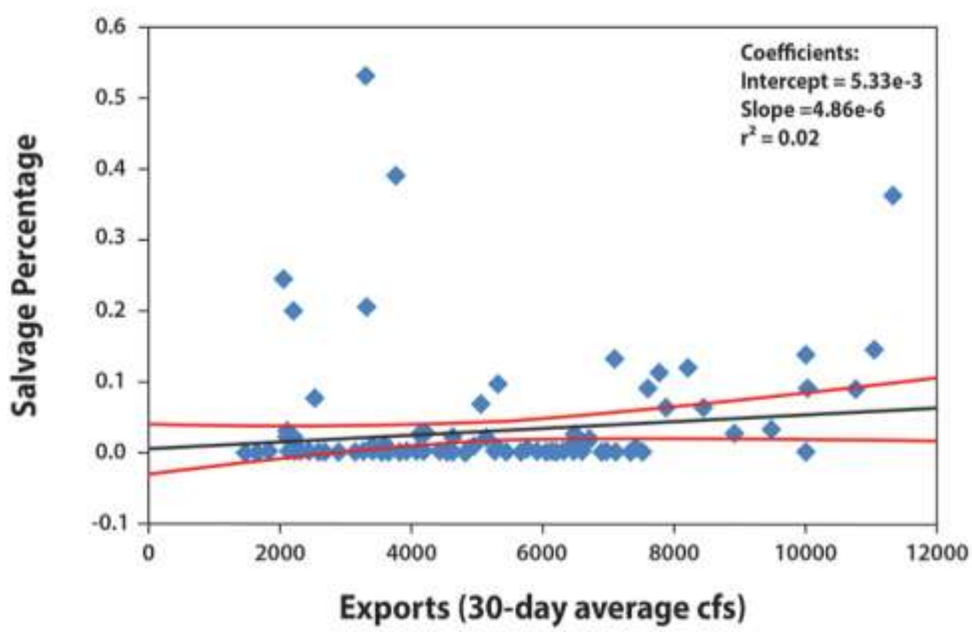

Figure 7-5. Relationship between SWP and CVP exports (30-day average) and percentage salvage (1980-2001).

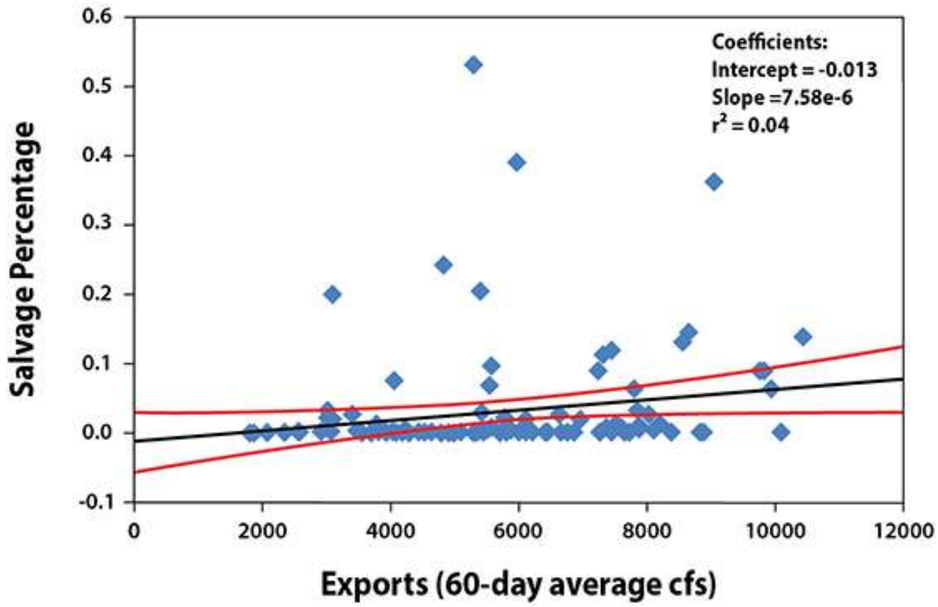

Figure 7-6. Relationship between SWP and CVP exports (60-day average) and percentage salvage (1980-2001).

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).

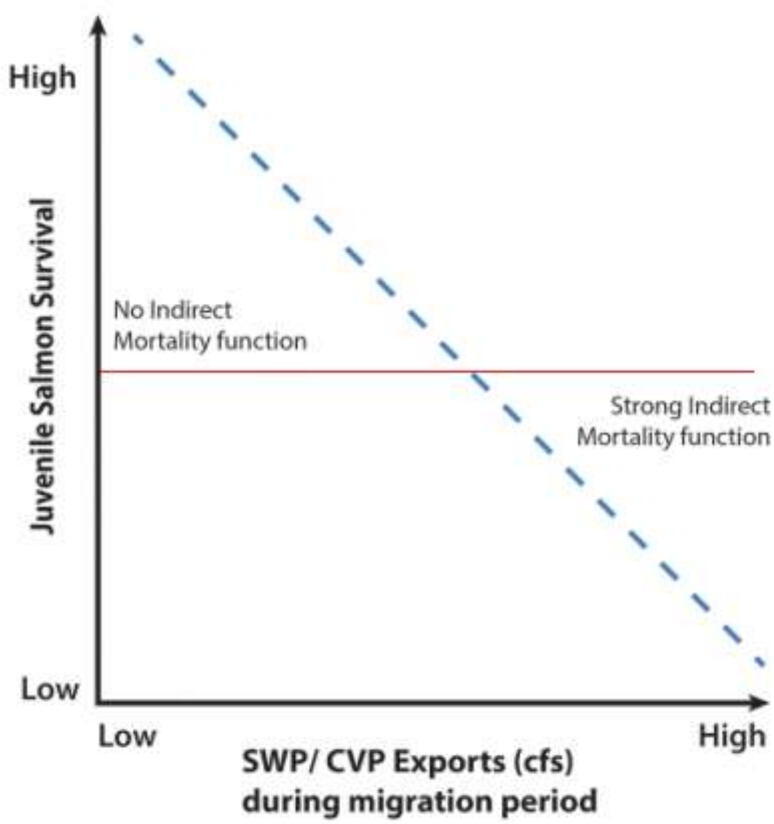

Figure 7-7. Hypothesis regarding the effect of SWP/CVP exports on indirect mortality of juvenile salmon.

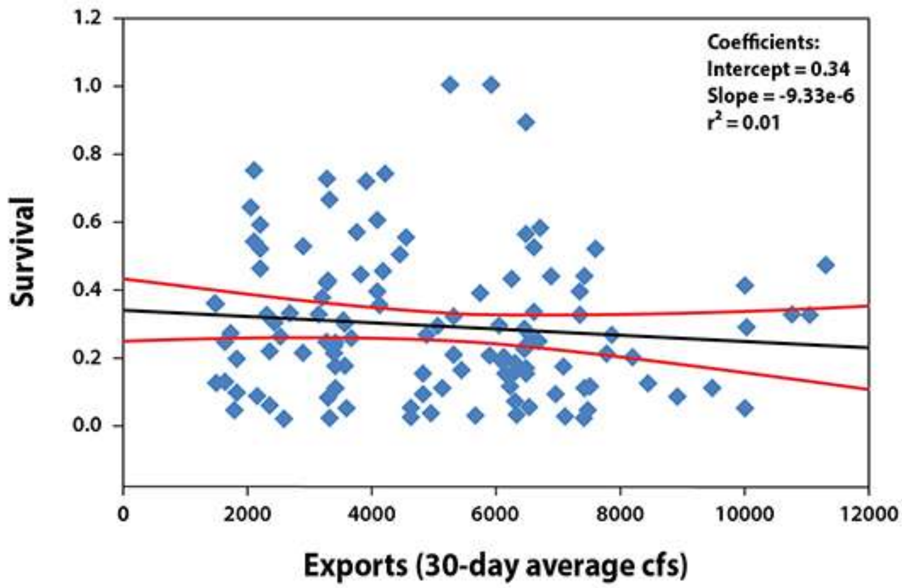

Figure 7-8. Relationship between SWP and CVP exports (30-day average) and Delta salmon survival (1980-2001).

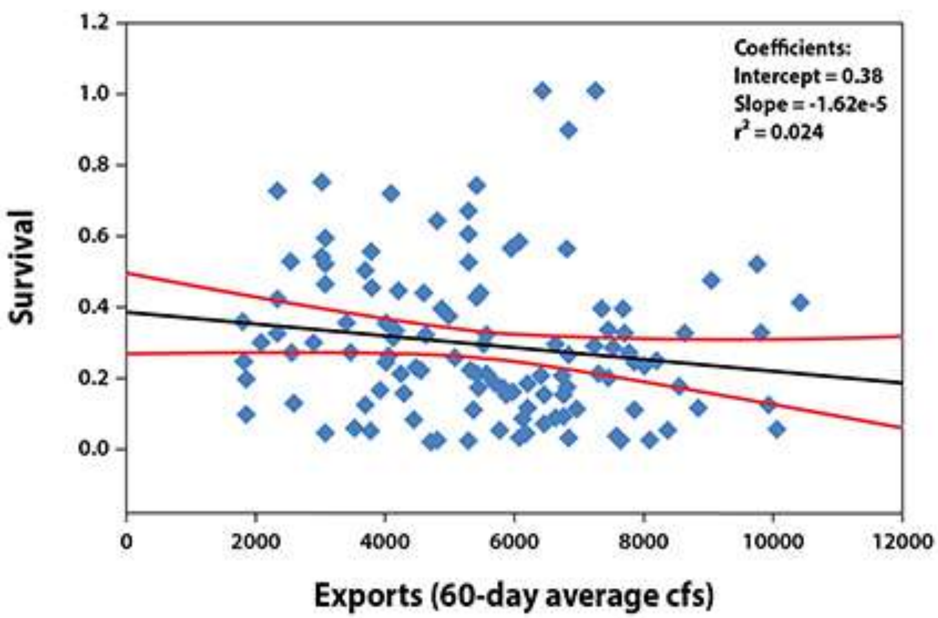

Figure 7-9. Relationship between SWP and CVP exports (60-day average) and Delta salmon survival (1980-2001).

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).

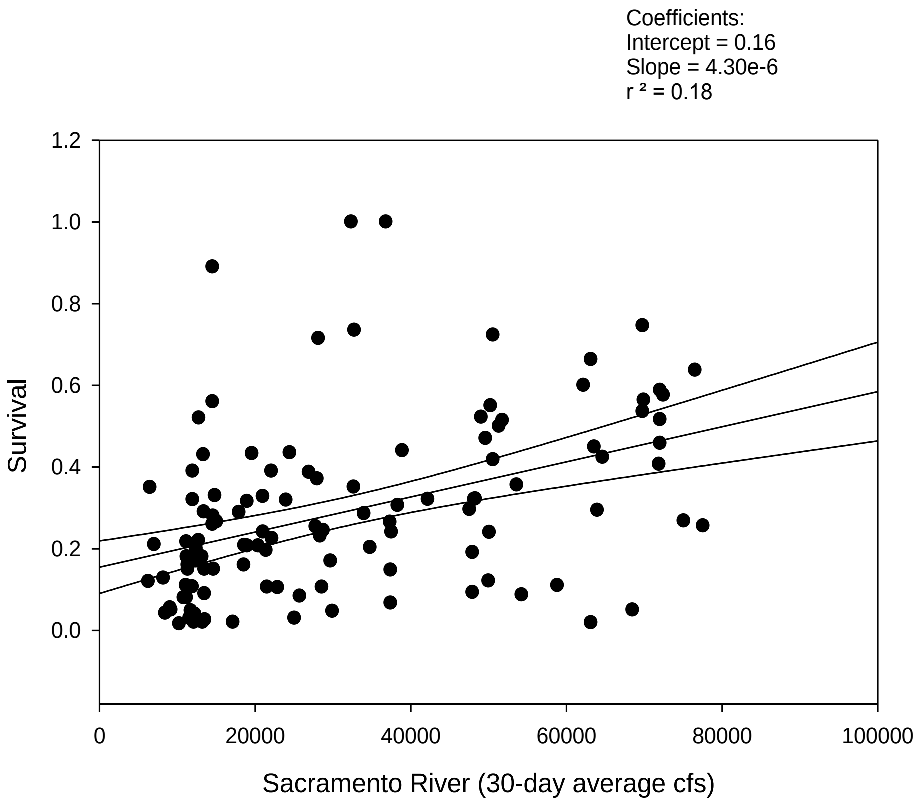

Figure 7-10. Relationship between Sacramento River flow (30-day average) and Delta salmon survival (1980-2001).

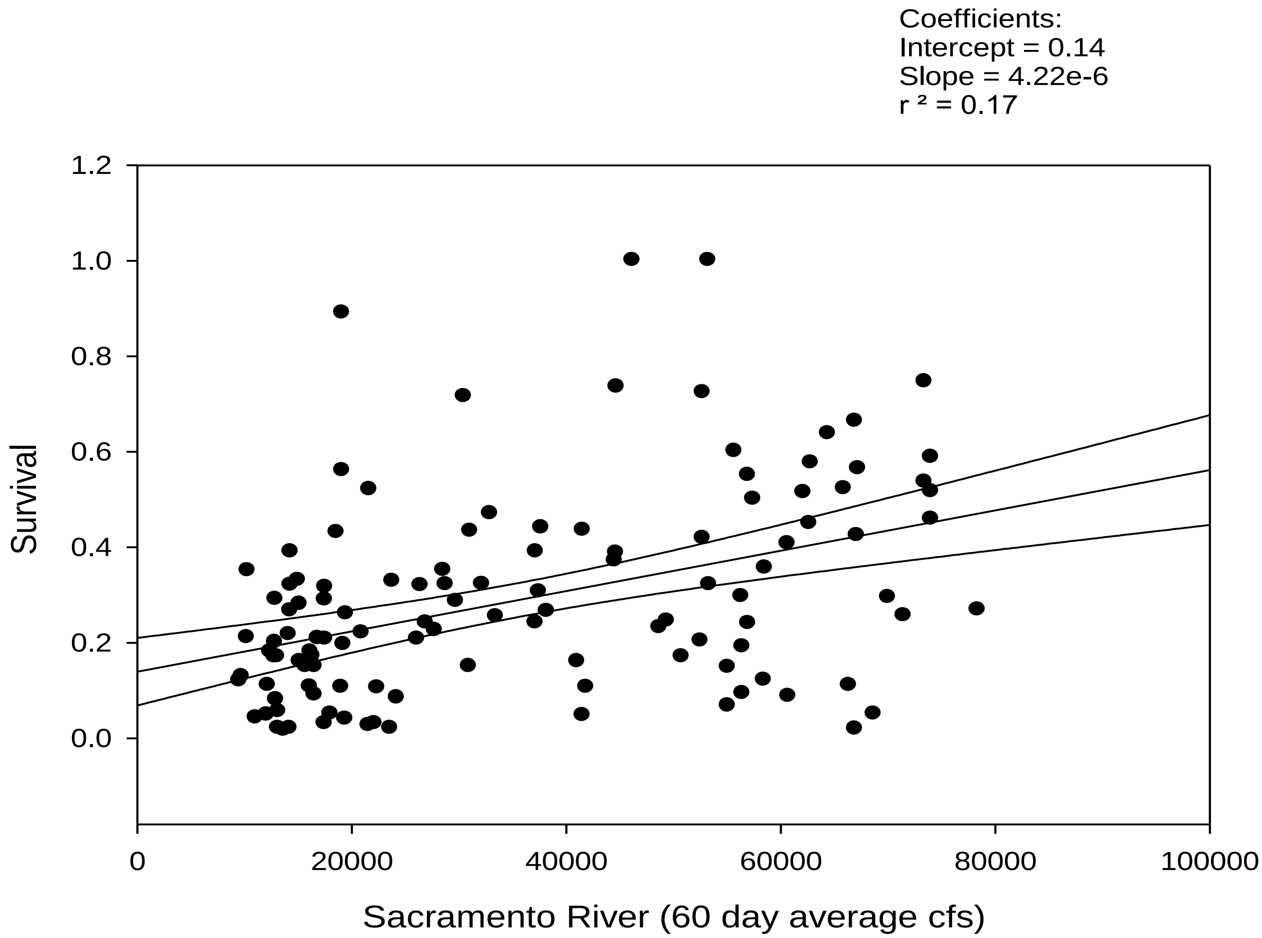

Figure 7-11. Relationship between Sacramento River flow (60-day average) and Delta salmon survival (1980-2001).

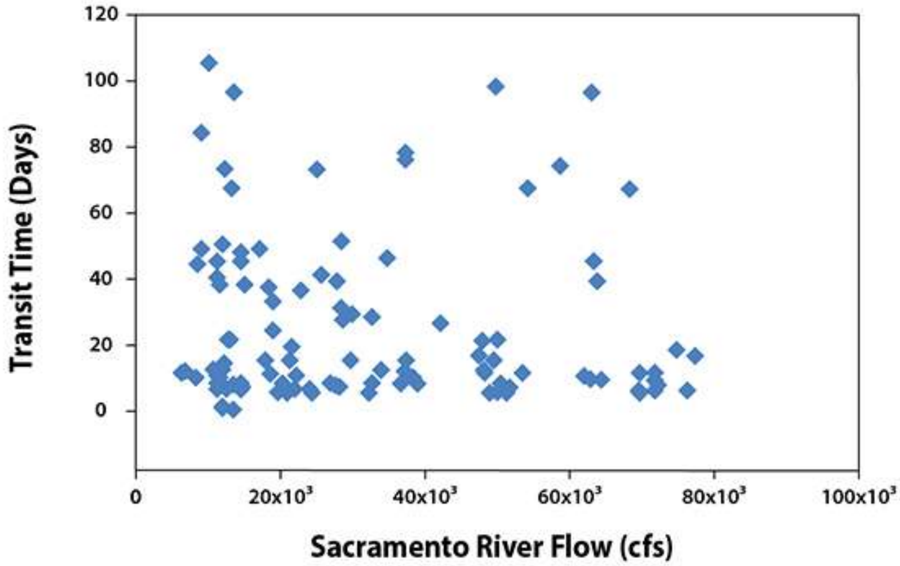

Figure 7-12. Relationship between Sacramento River flow (30-day average) and salmon transit time (1980-2001).

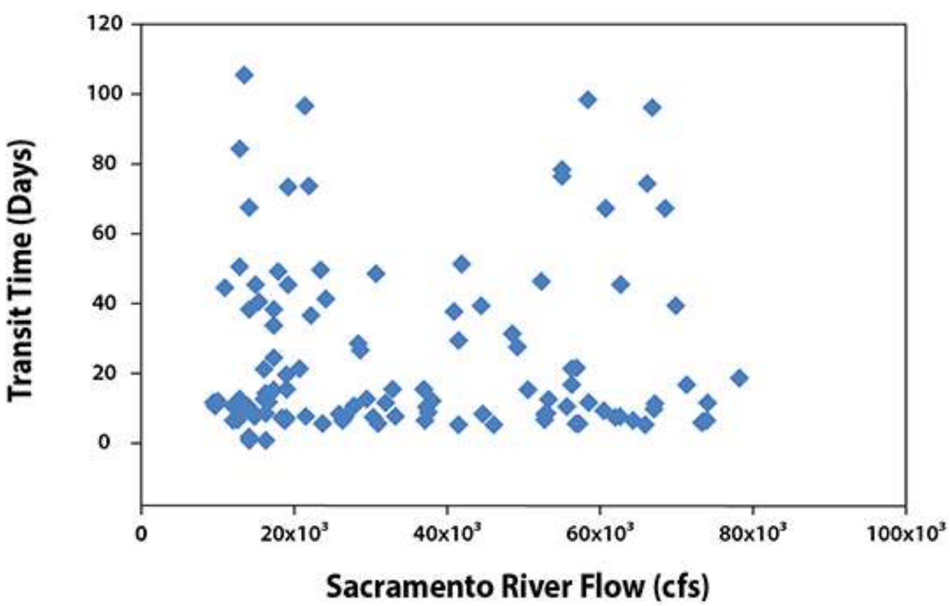

Figure 7-13. Relationship between Sacramento River flow (60-day average) and salmon transit time (1980-2001).

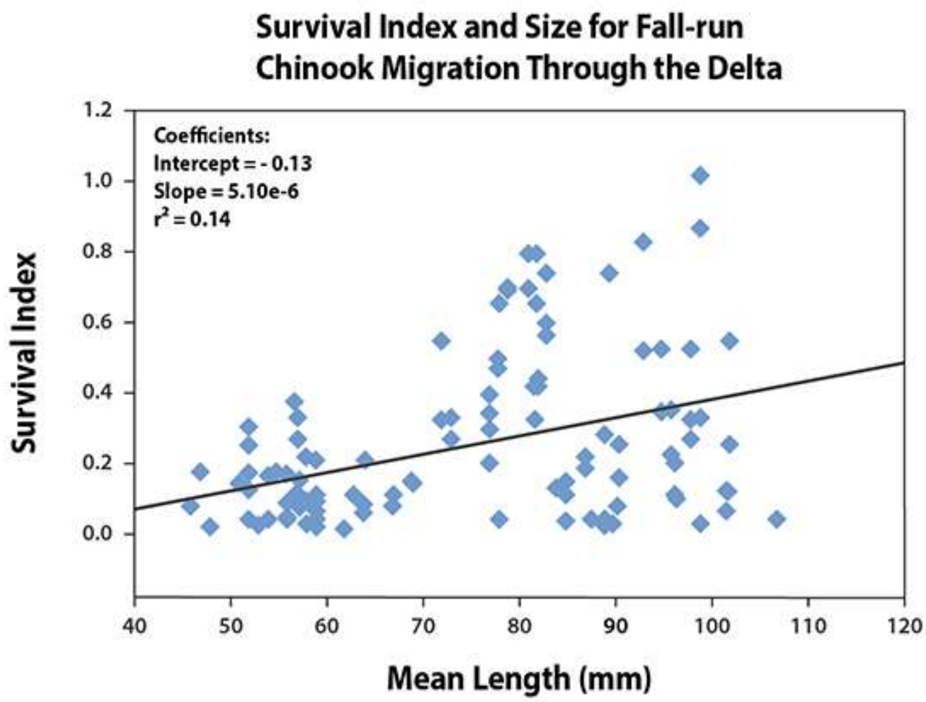

Figure 7-14. Relationship between salmon length at release and survival (1980-2001).

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.

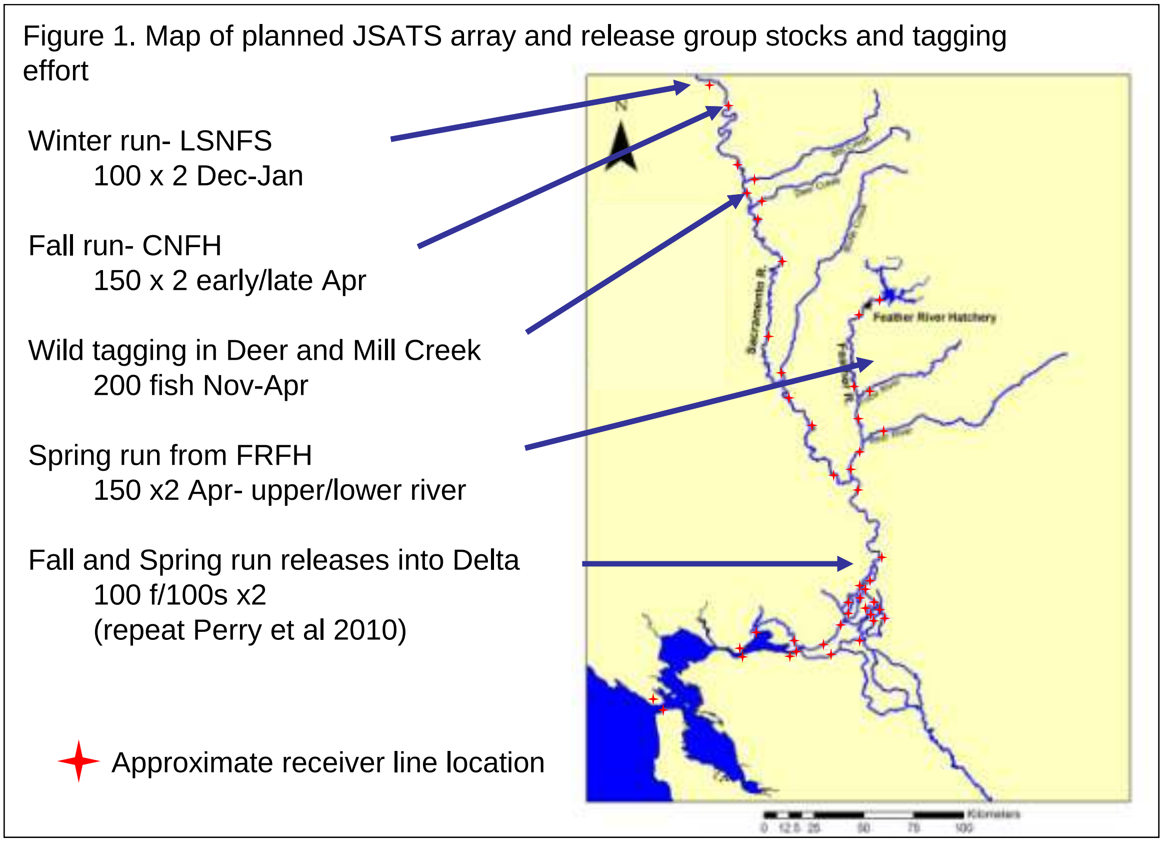

Figure 7-15. **Map of the study area for acoustic tracking of hatchery and wild juvenile salmon on the Sacramento River, Delta, and estuary (Source: Hayes 2012).**

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).

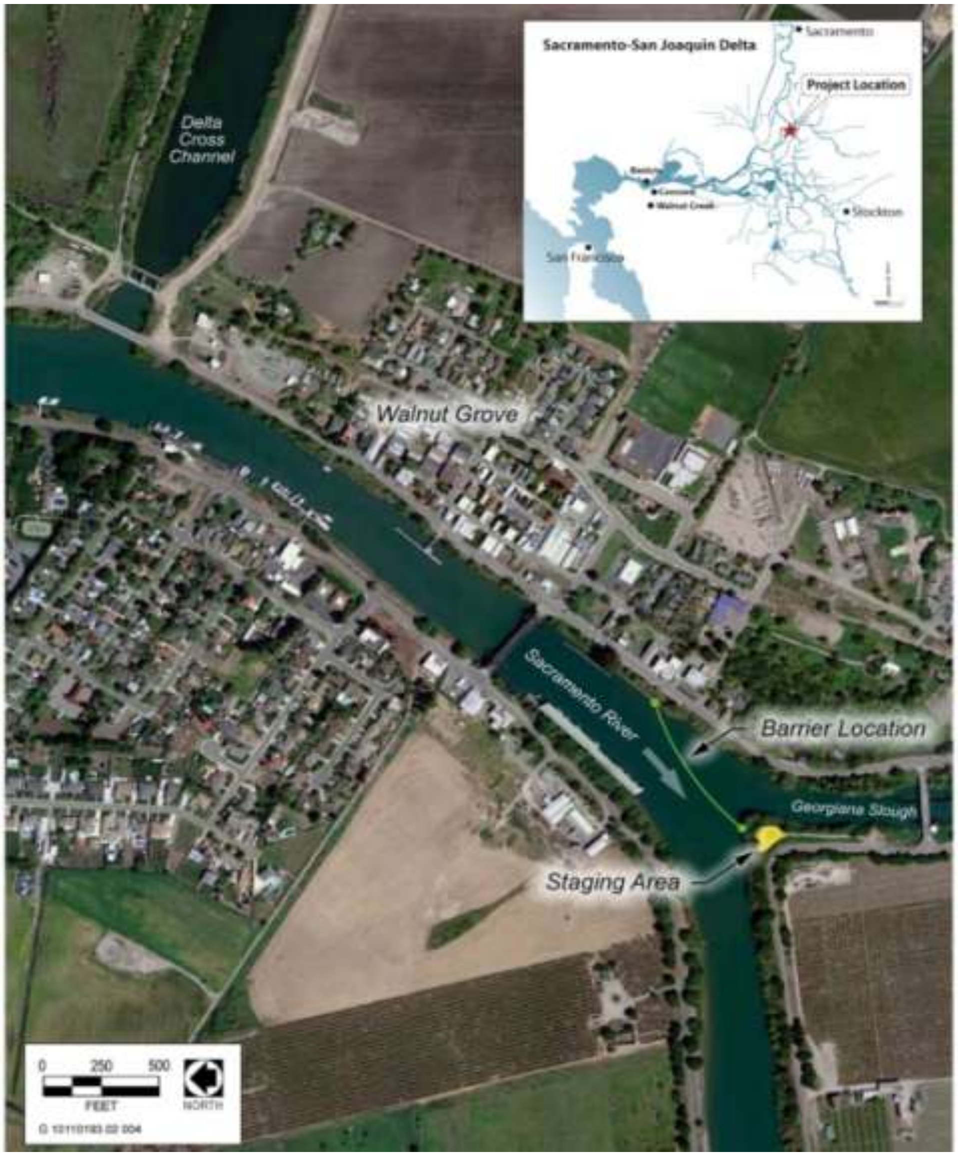

Figure 7-17. Sacramento River in the vicinity of Walnut Grove showing the location of the non-physical barrier tested in 2011 and 2012 (DWR 2012).

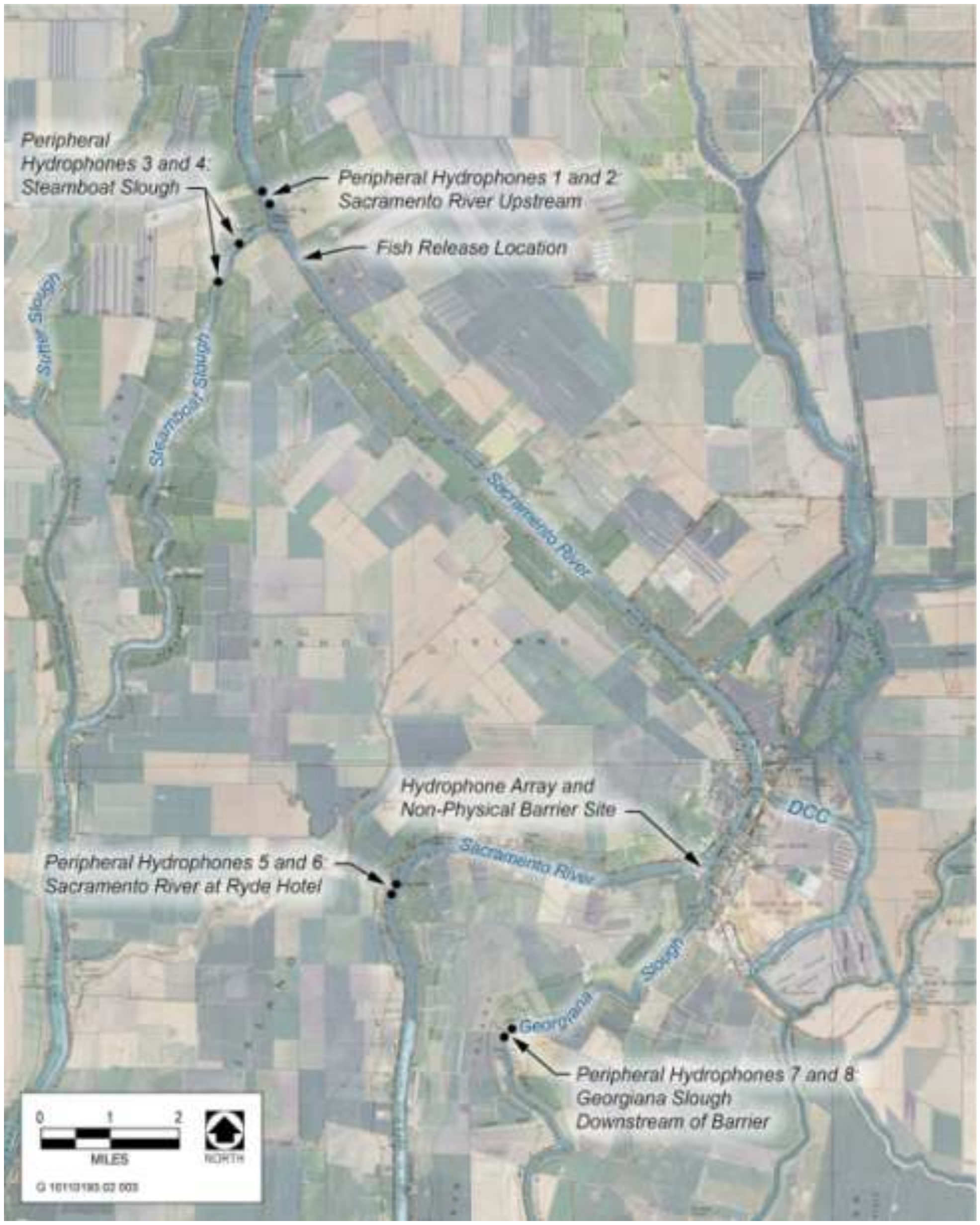

Figure 7-18. Map showing the basic experimental design for the 2011 and 2012 Georgiana Slough non-physical barrier acoustic tag tests (DWR 2012).

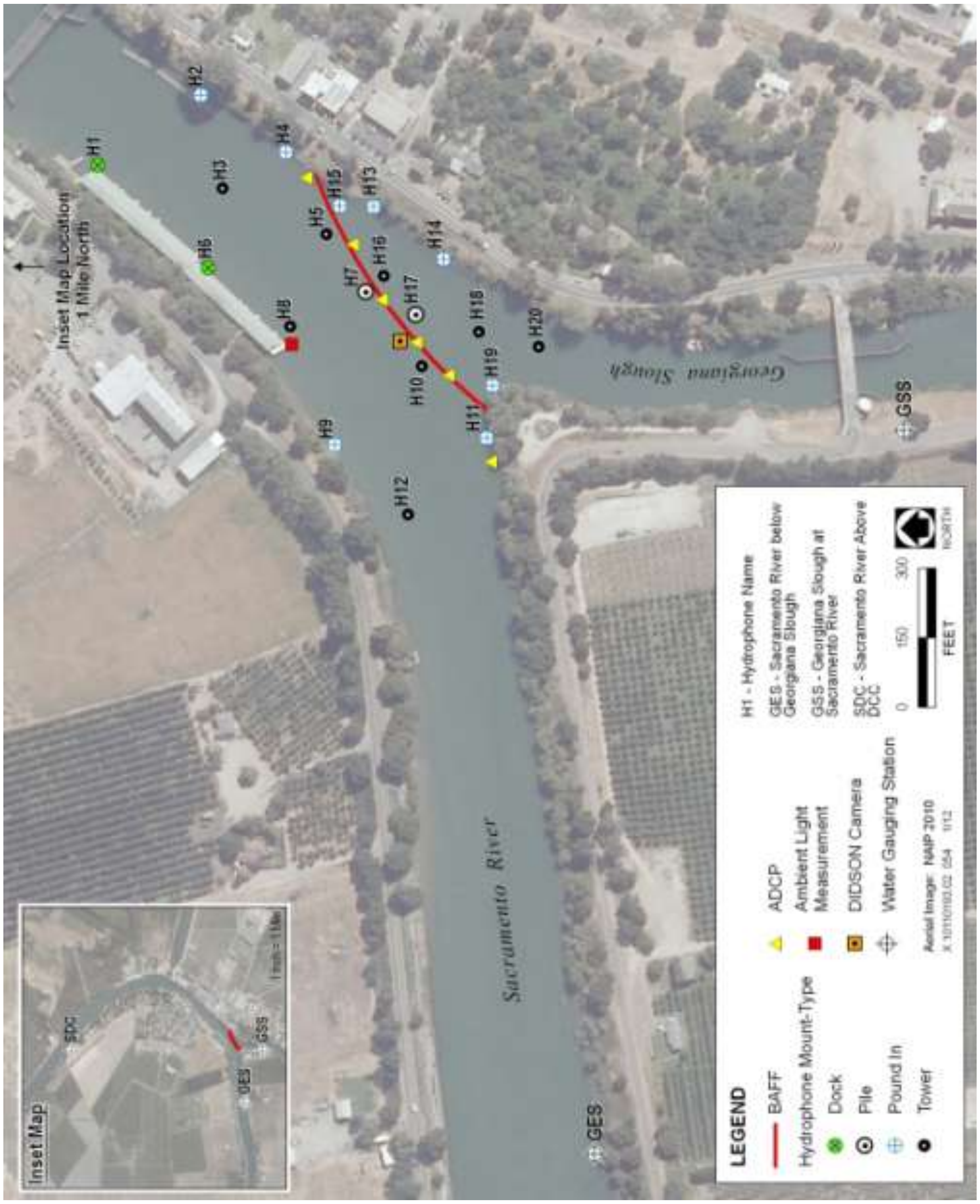

Figure 7-19. Deployment of 3-dinensional acoustic tag detector array associated with the Georgiana Slough non-physical barrier tests (DWR 2012).

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).

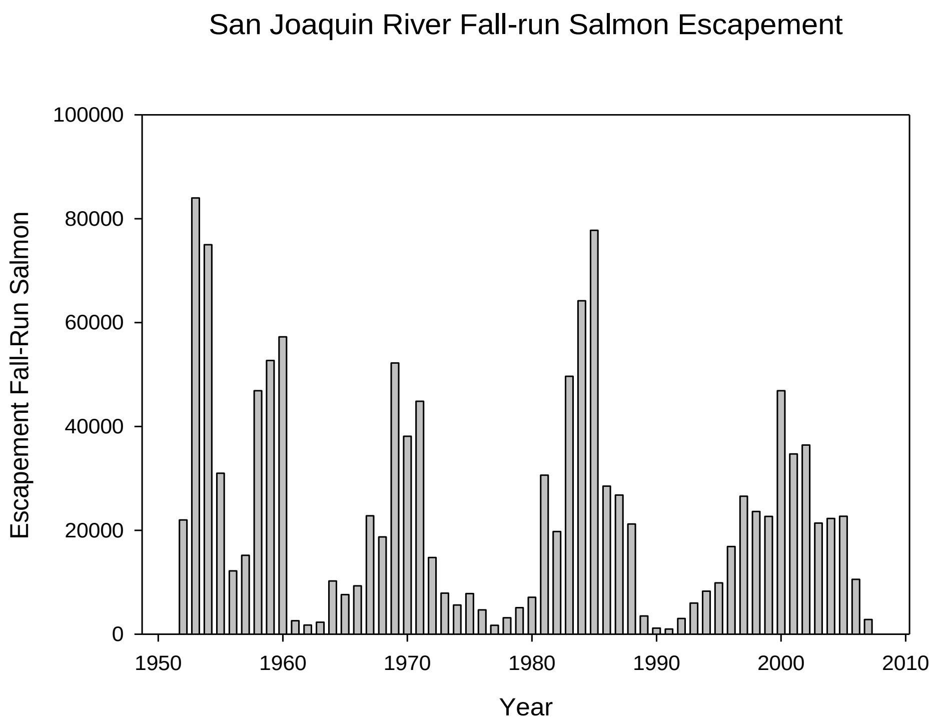

Figure 8-1. Adult fall-run Chinook salmon escapement to the San Joaquin River basin (Source: GranTab 2011).

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.

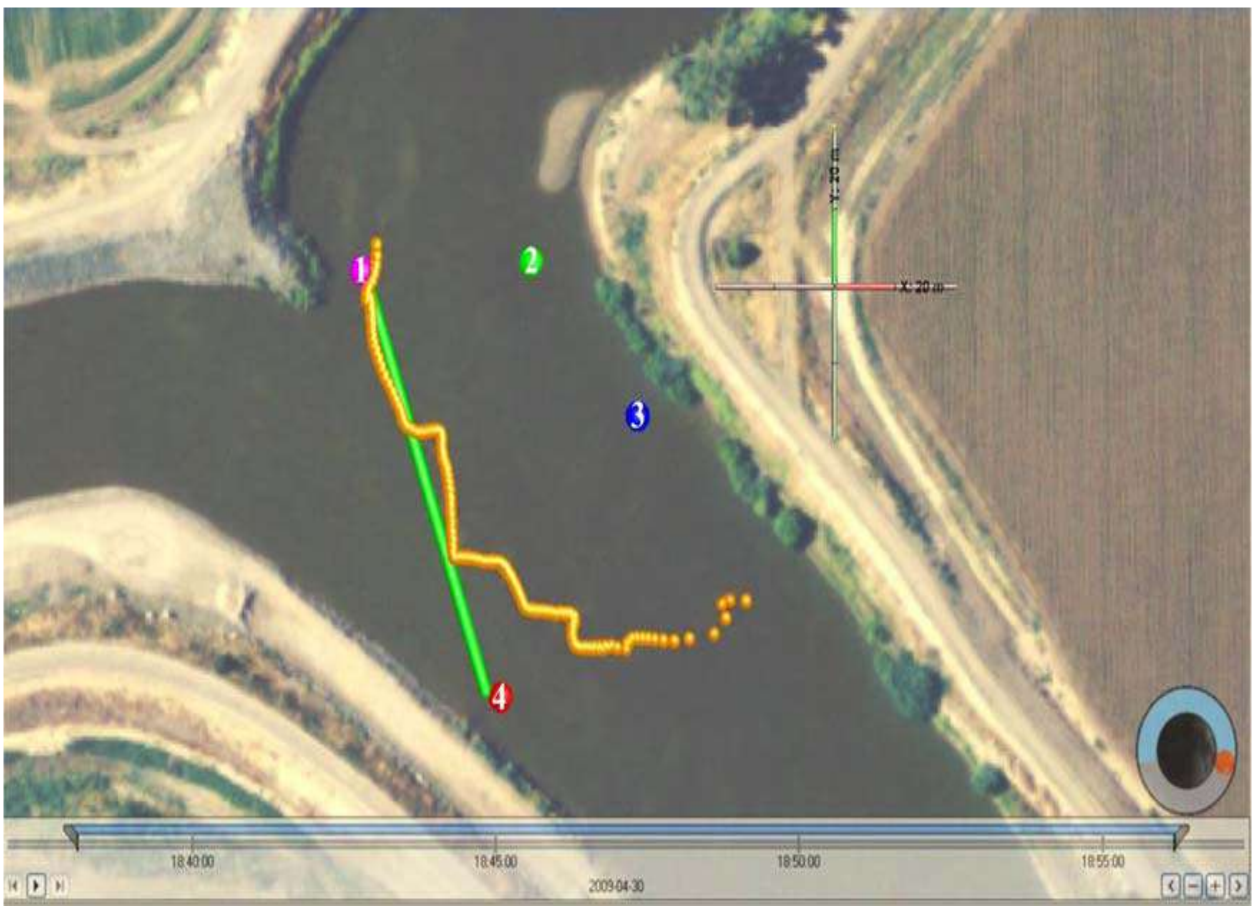

Figure 8-2. Acoustic tag tracking results for a juvenile Chinook salmon (yellow track) that was effectively guided downstream by the non-physical barrier (green line) at the Head of Old River (Source Bowen *et al.* 2009).

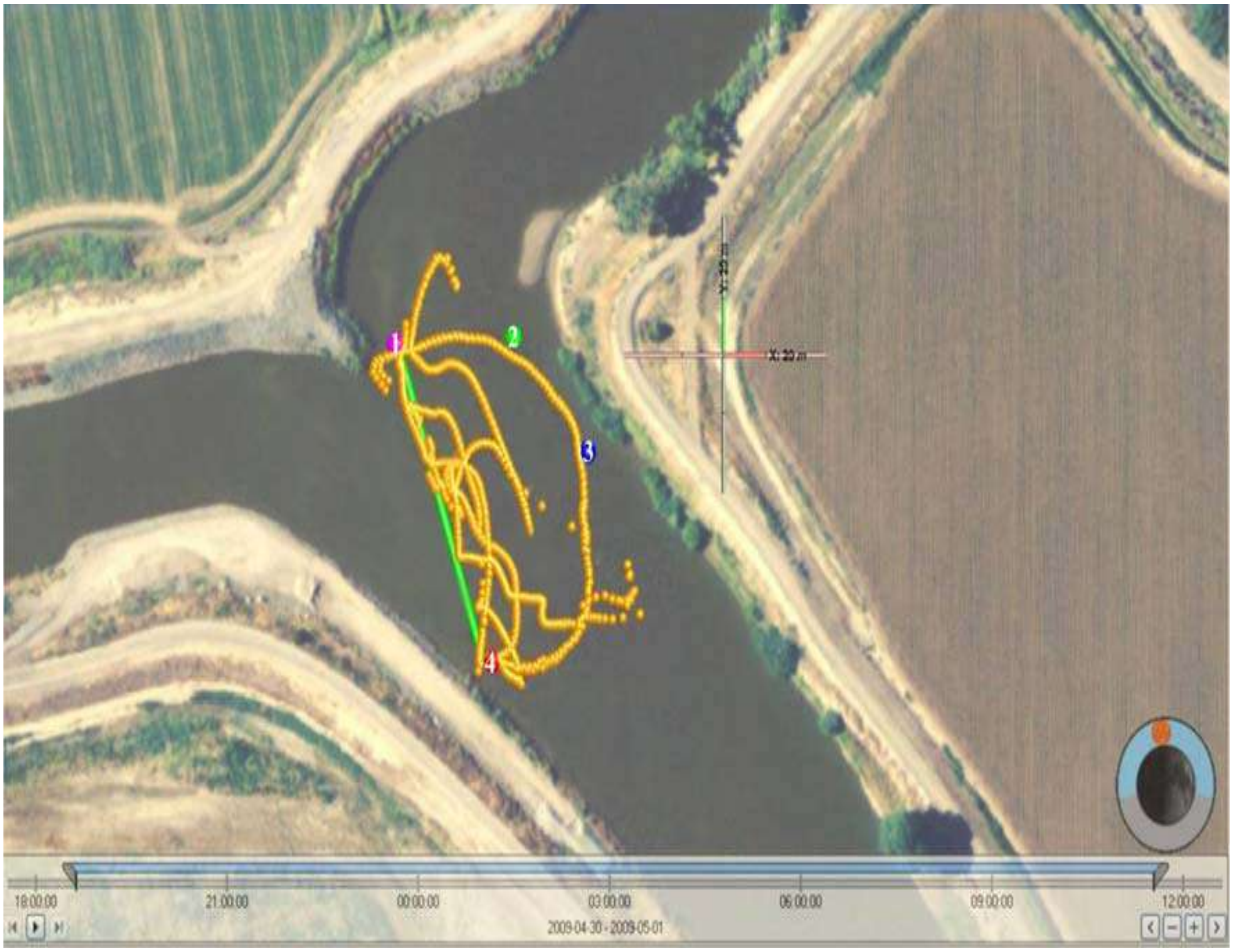

Figure 8-3. Acoustic tag tracking results for a juvenile Chinook salmon (yellow track) that was preyed upon in the vicinity of the non-physical barrier (green line) at the Head of Old River (Source Bowen *et al.* 2009).

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.

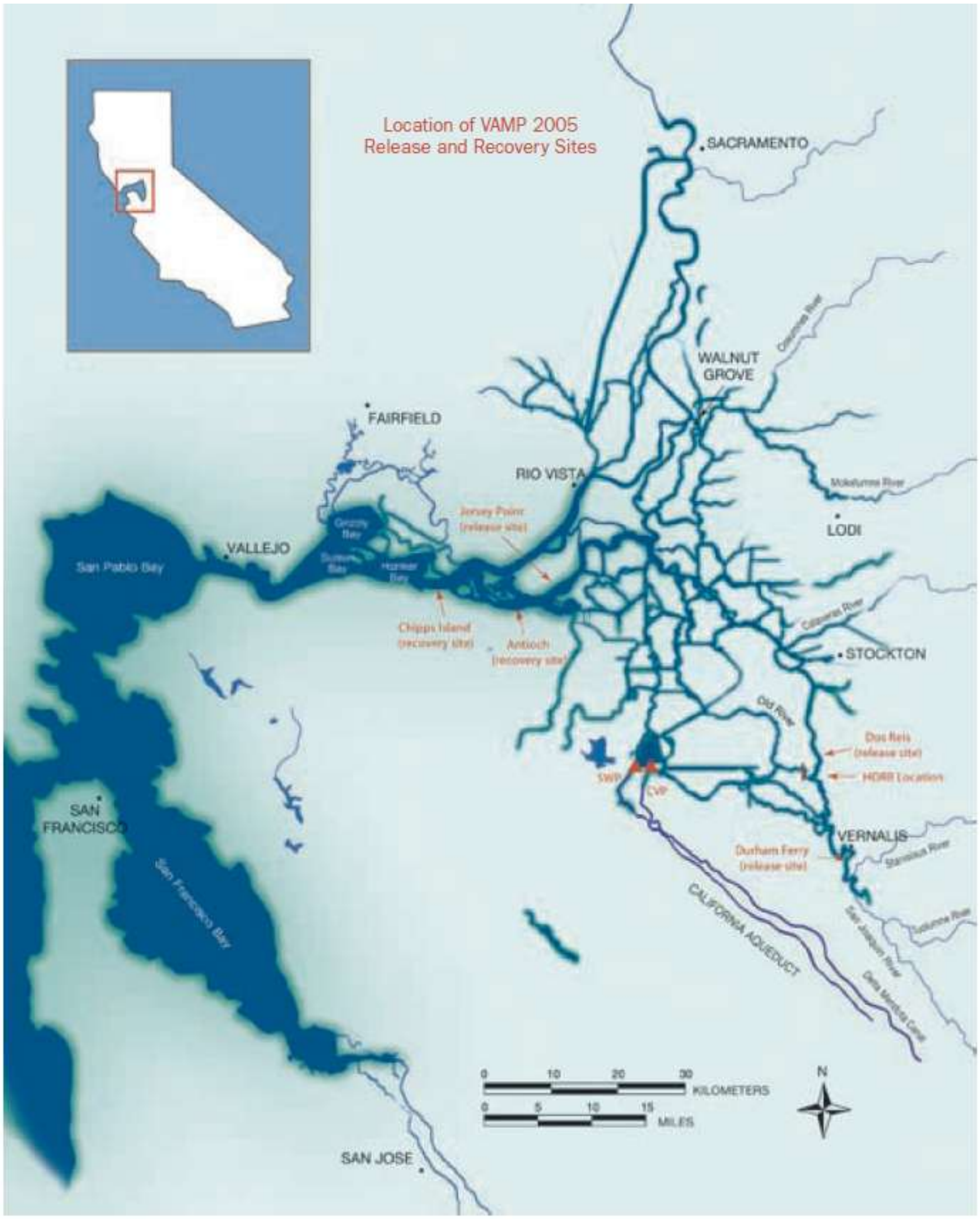

Figure 8-4. Map showing the location of VAMP survival study release and recapture sites for CWT juvenile Chinook salmon.

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

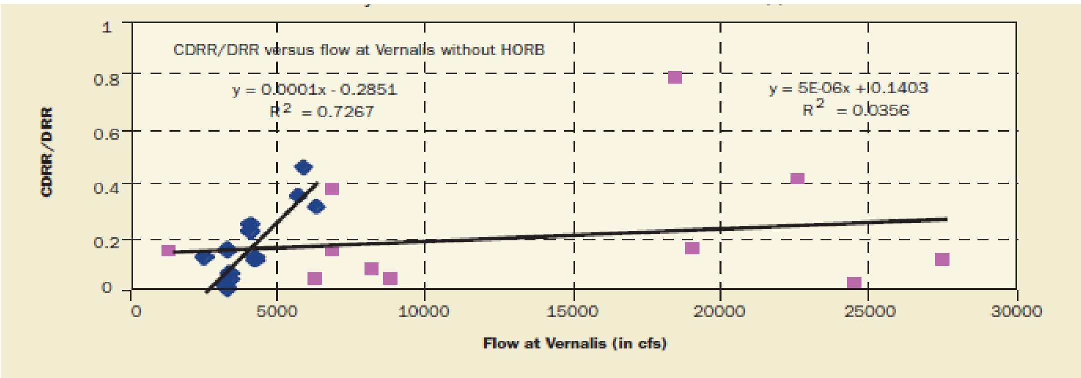

Figure 8-5. Results of CWT survival studies on the lower San Joaquin River as a function of average flow at Vernalis over a 10-day period after release with and without the Head of Old River Barrier (Source: SJRGA 2006).

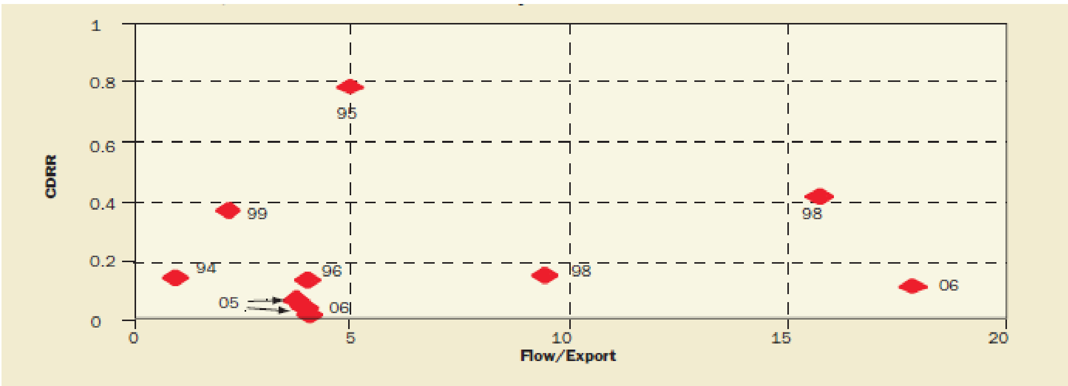

Figure 8-6. Survival of CWT juvenile Chinook salmon released into the San Joaquin River at Durham Ferry and Mossdale (corrected for Jersey Point controls) as a function of the average Vernalis flow/Export rate over a 10 day period following release without the Head of Old River Barrier (Source: SJRGA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

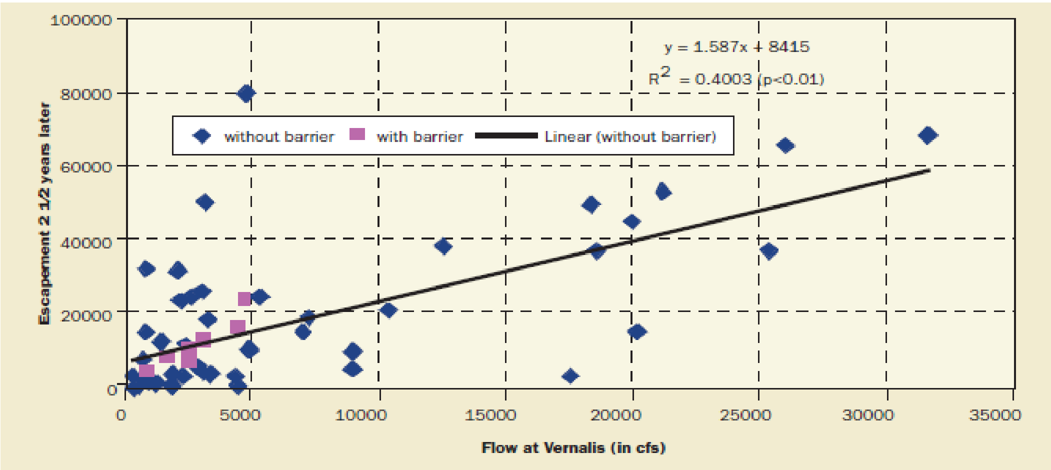

Figure 8-7. Relationship between adult Chinook salmon escapement and average Vernalis flows 2-1/2 years earlier (Source: SJRGA 2006).

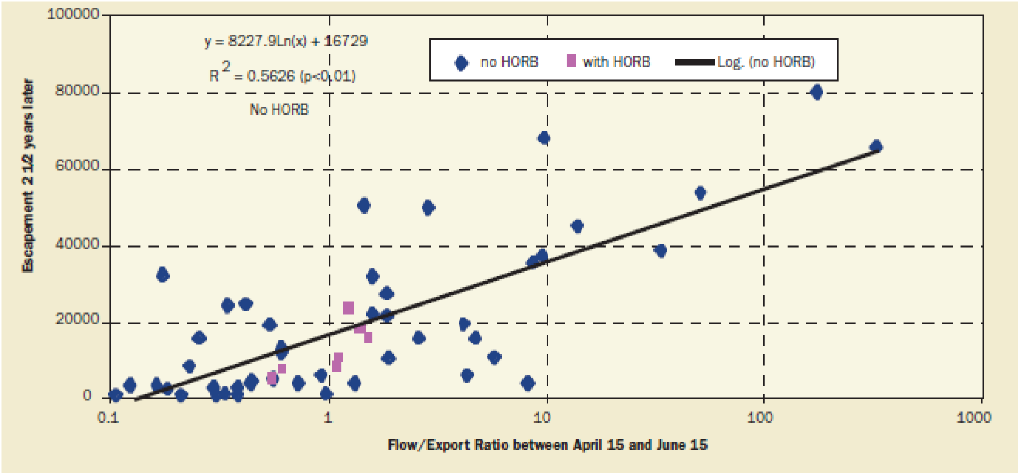

Figure 8-8. Relationship between adult Chinook salmon escapement and average Vernalis flow/Export ratio 2-1/2 years earlier (Source: SJRGA 2006).

- 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.

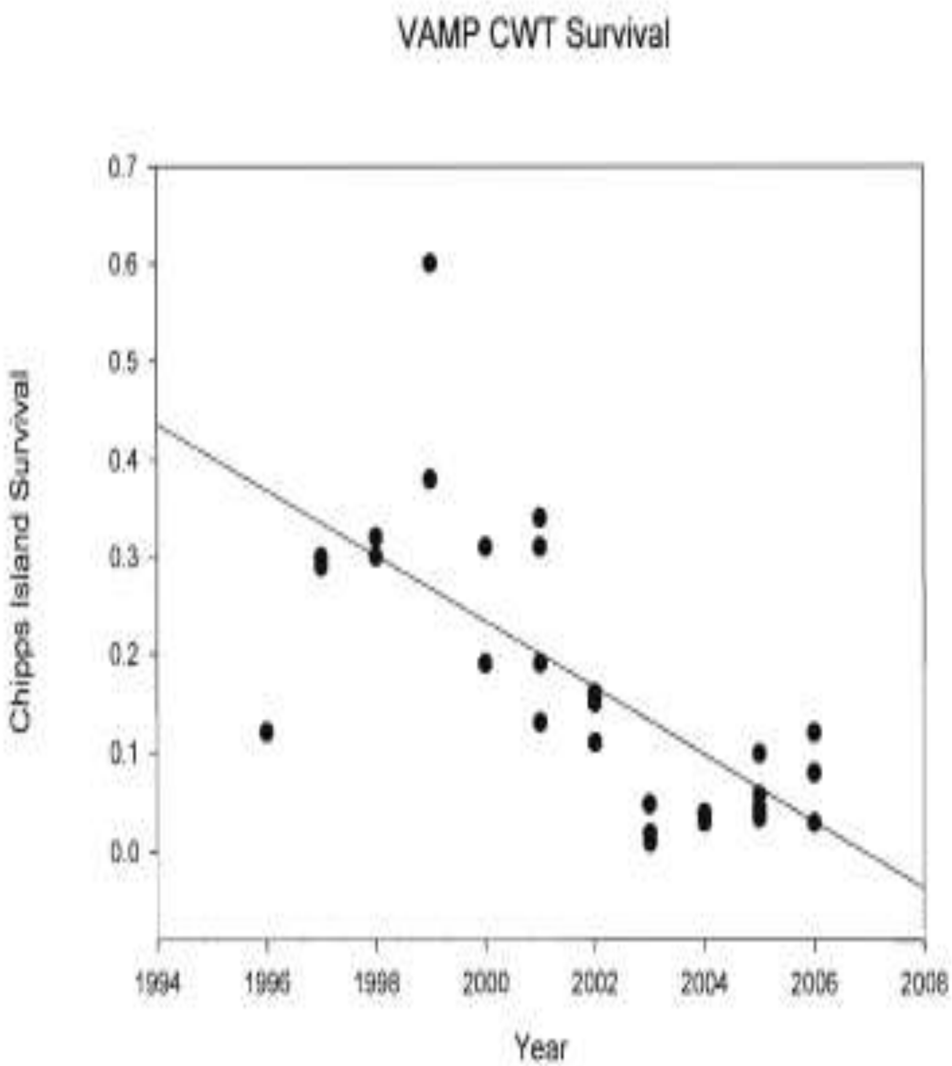

Figure 8-9. Trend in juvenile fall-run Chinook salmon survival in the lower San Joaquin River and Delta measured during VAMP studies (Source: SJRGA 2006).

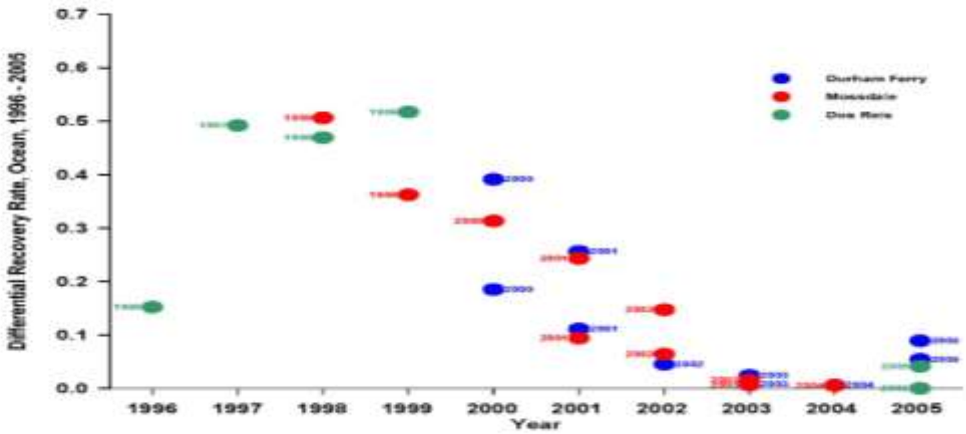

Exhibit 2. Declining trend over time in differential survival of Chinook salmon emigrating from the lower San Joaquin River as reflected in recaptures in the ocean fishery (Source: S. Greene, DWR, pers com.).

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).

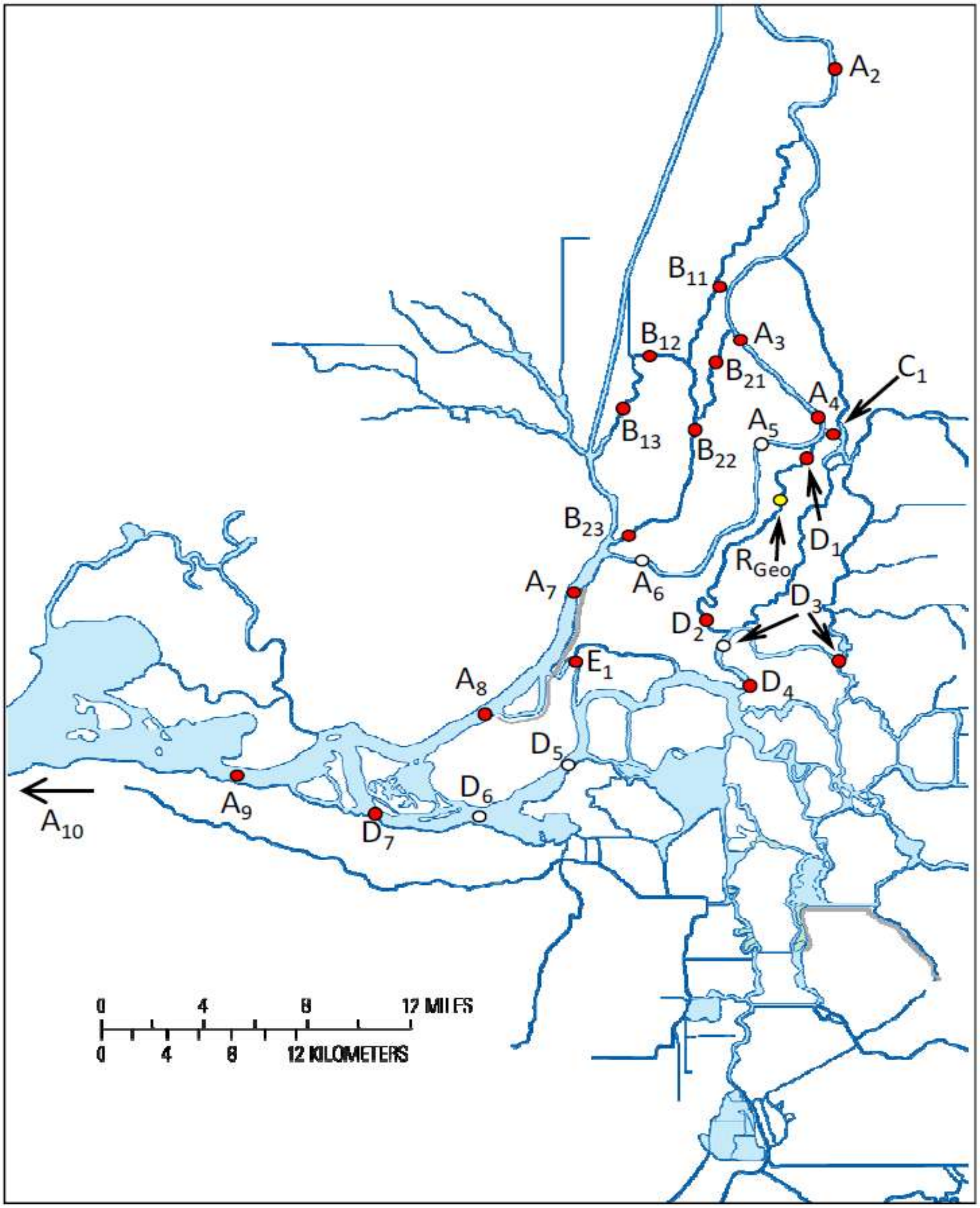

Figure 9-1. Acoustic receiver sites monitored in the north Delta and Sacramento River during acoustic tag studies using late fall-run Chinook salmon during the winter of 2009 (Source: Perry 2010). Open circles denote telemetry stations used in 2008 but not in 2009. The Sacramento release site was 19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

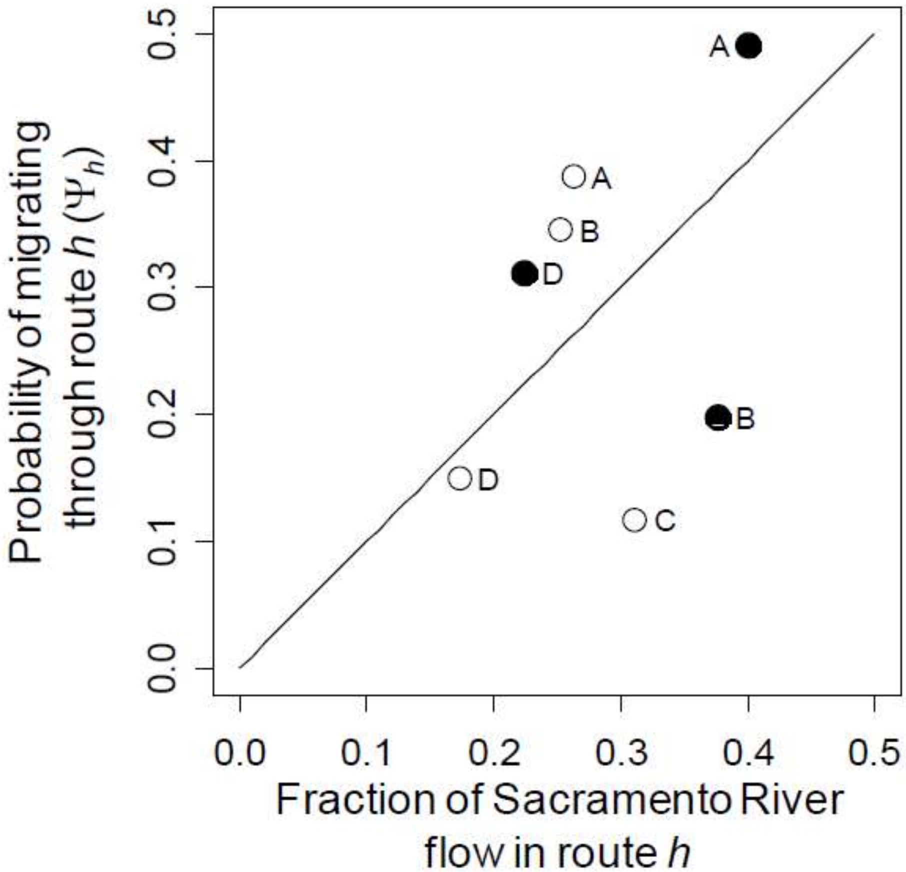

Figure 9-2. Relationship between the fraction of Sacramento River water flowing into various north Delta channels and the probability of acoustically tagged juvenile late fall-run Chinook salmon migrating through the route (Source: Perry 2010). The open circles represent releases in December 2007 and 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.

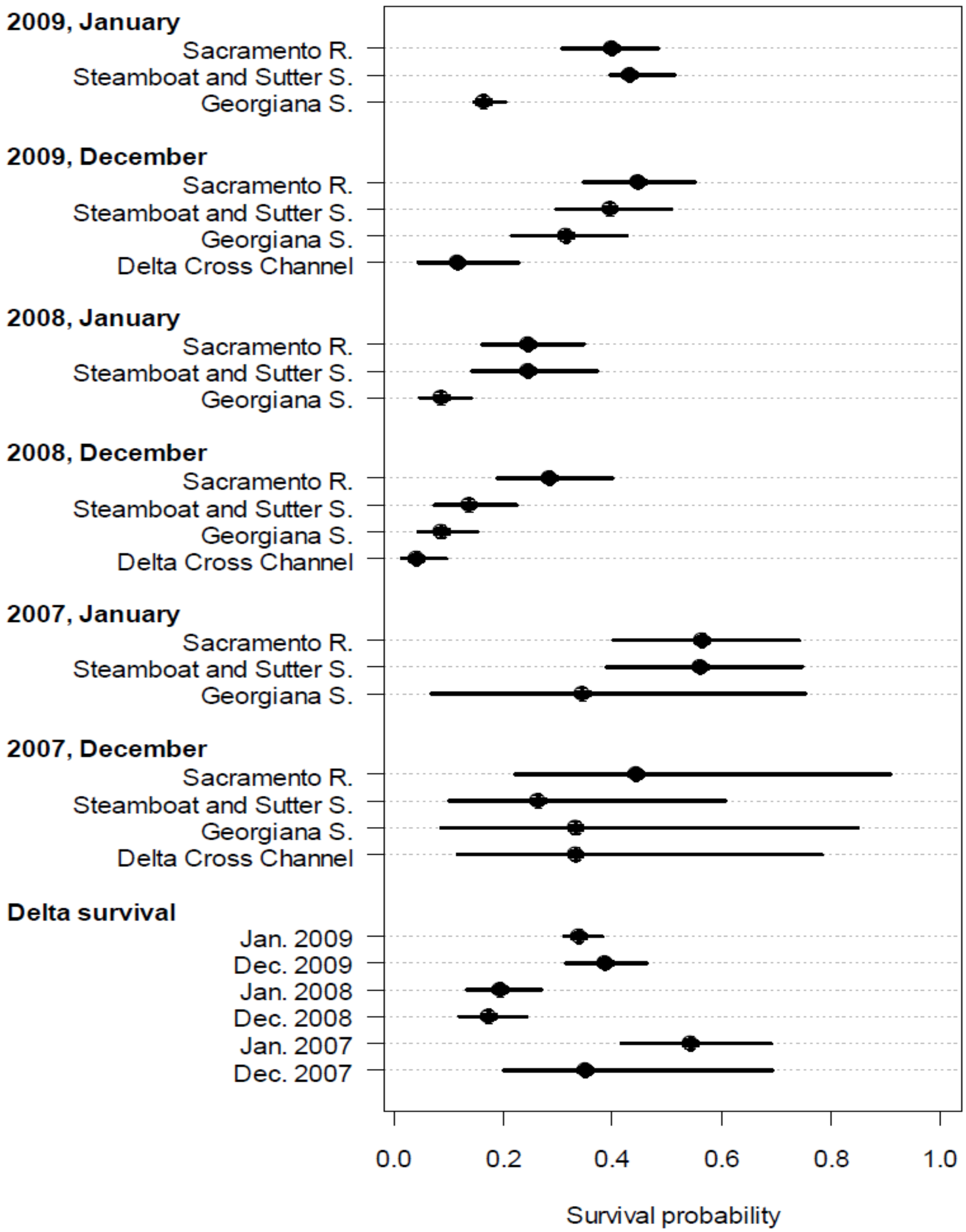

Figure 9-3. Route-specific survival estimates for migration of acoustically tagged juvenile late fall-run Chinook salmon in north Delta channels in 2007-2009 (source: Perry 2010).

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.

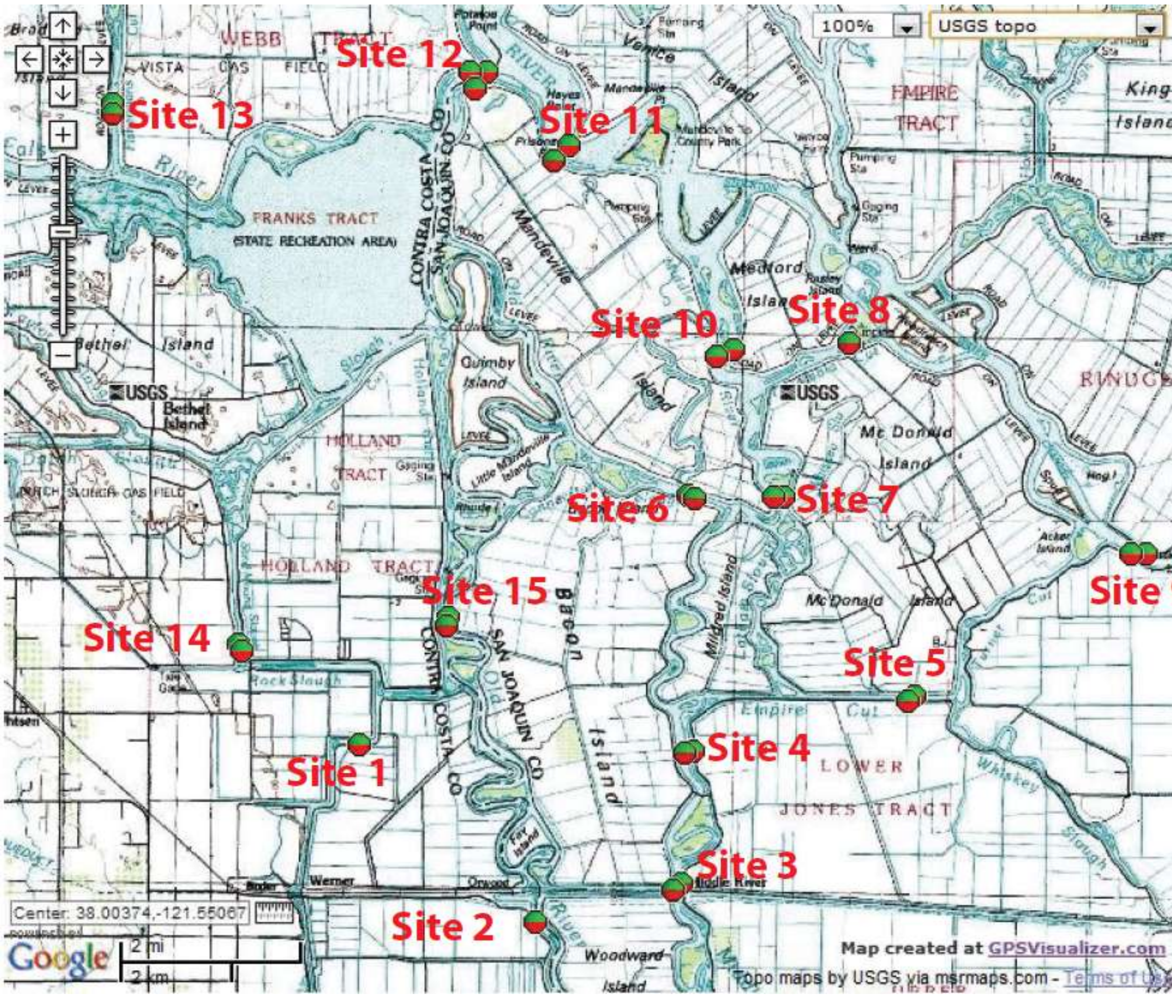

Figure 9-4. Map of the central and south Delta showing acoustic tag monitoring locations deployed as part of the 2012 Stipulation Study of juvenile steelhead migration through the Delta in response to OMR flows.

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

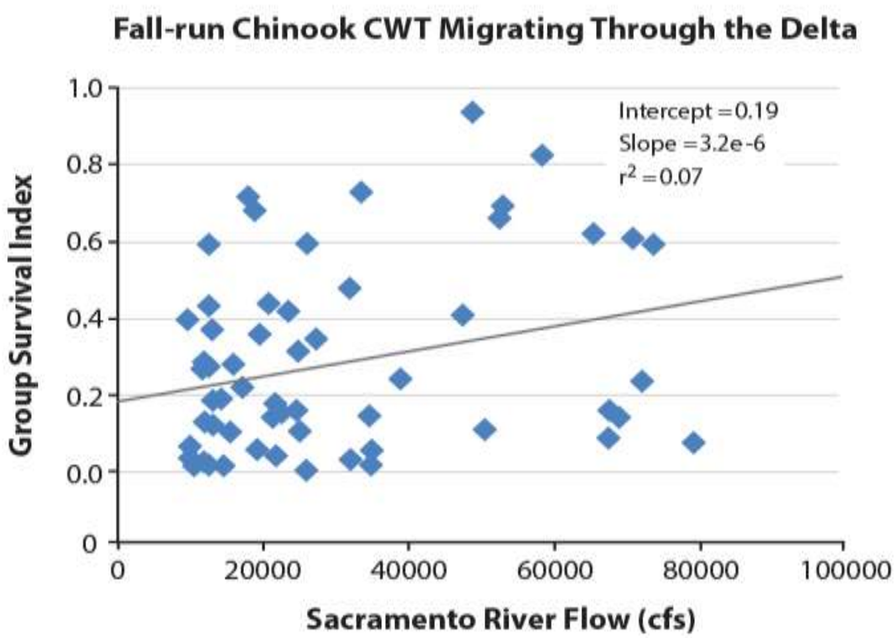

Figure 9-5. Relationship between average Sacramento River flow at Freeport over a 14-day period after release and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

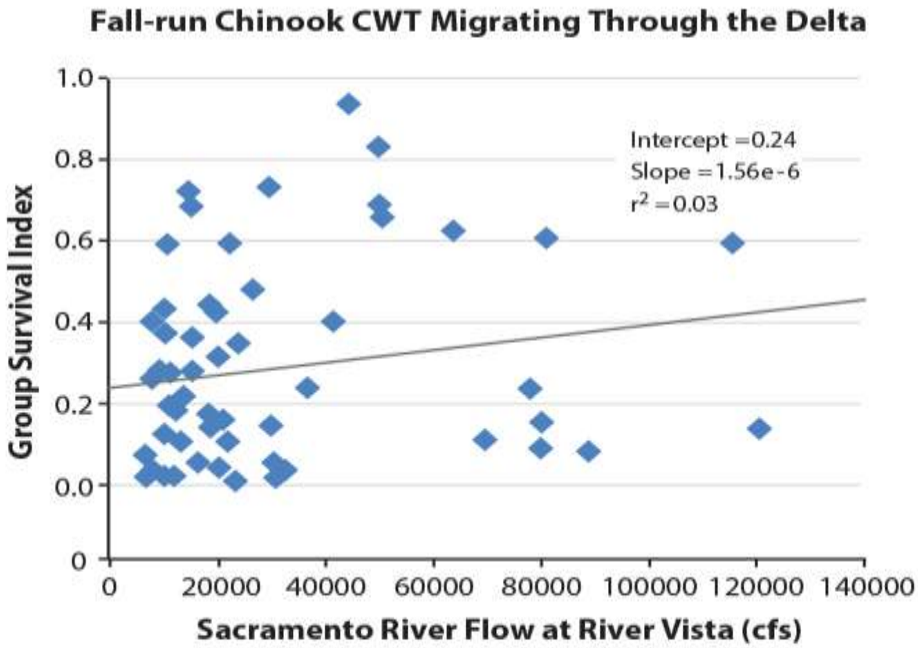

Figure 9-6. **Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.**

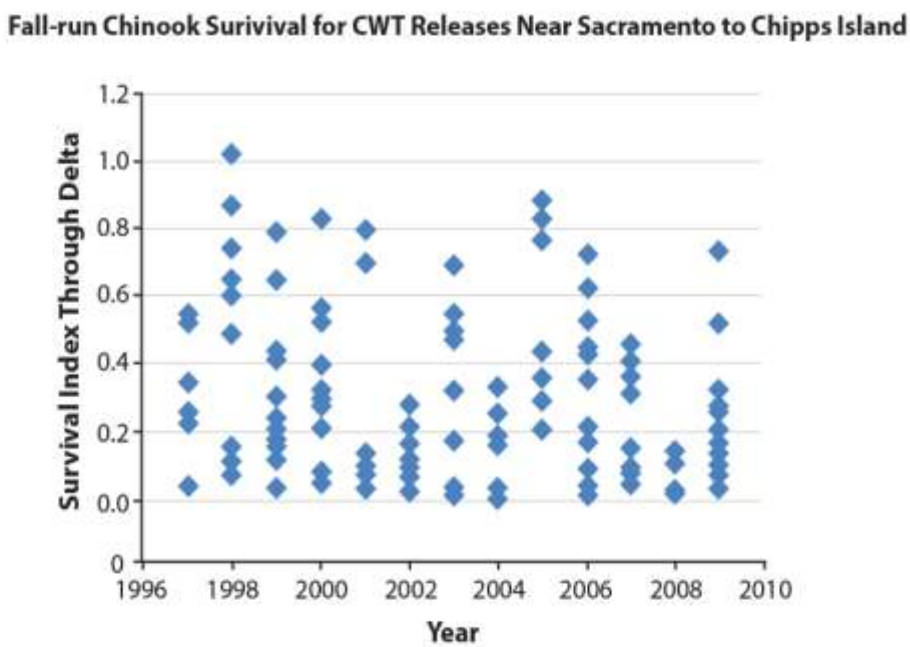

Figure 9-7. **Relationship between year and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.**

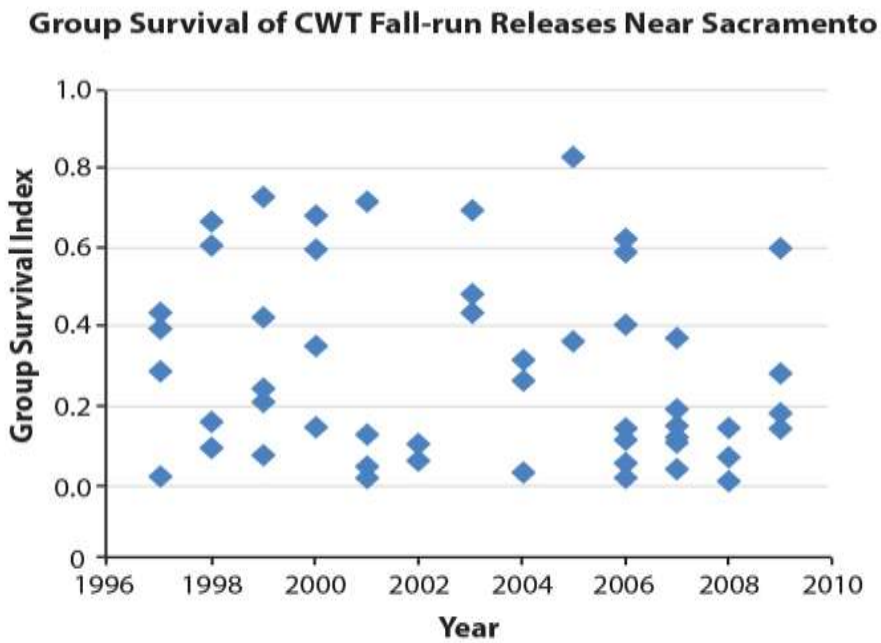

Figure 9-8. Relationship between year and juvenile fall-run salmon group survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

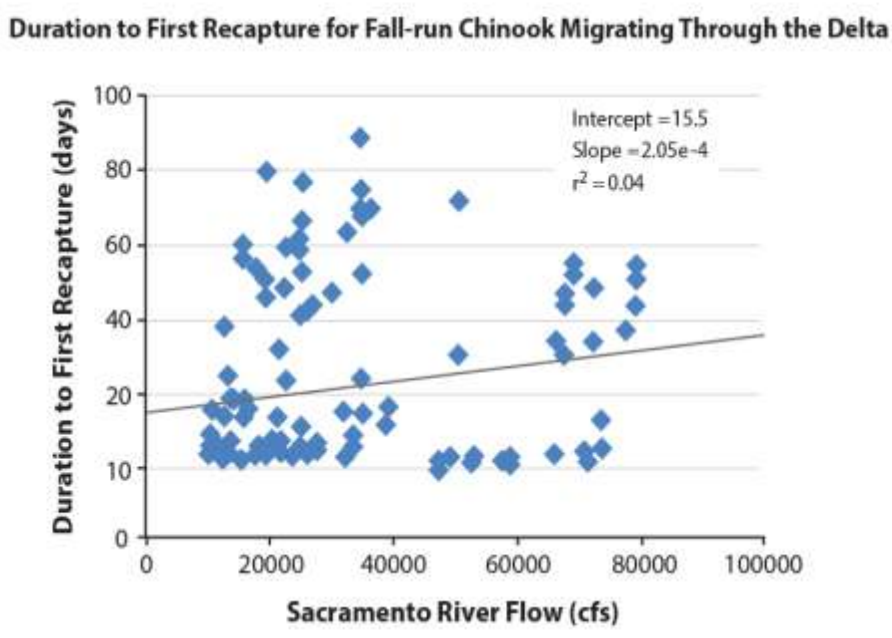

Figure 9-9. Relationship between average Sacramento River flow at Freeport over a 14-day period after release and the duration to first recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.

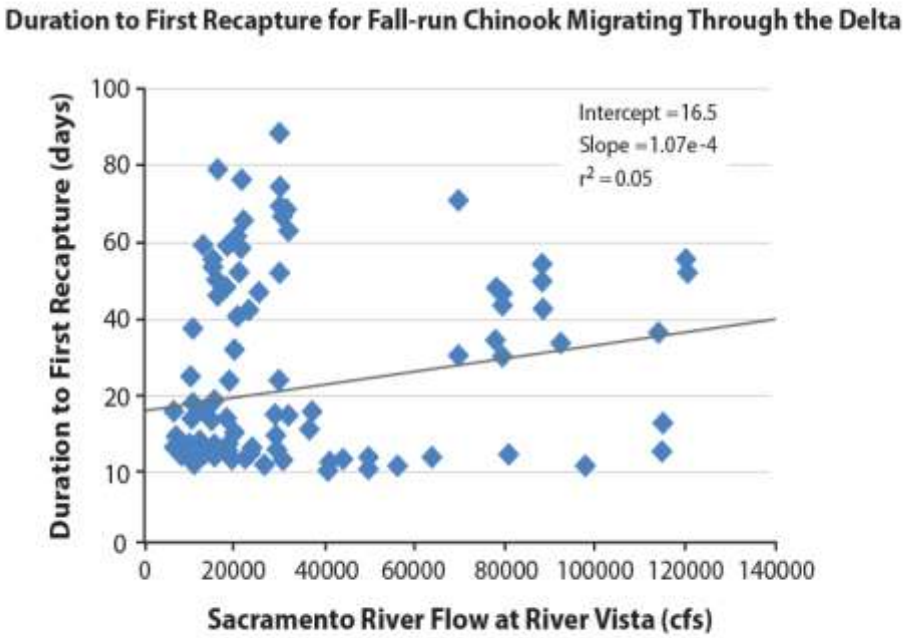

Figure 9-10. Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and the duration to first recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.

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.

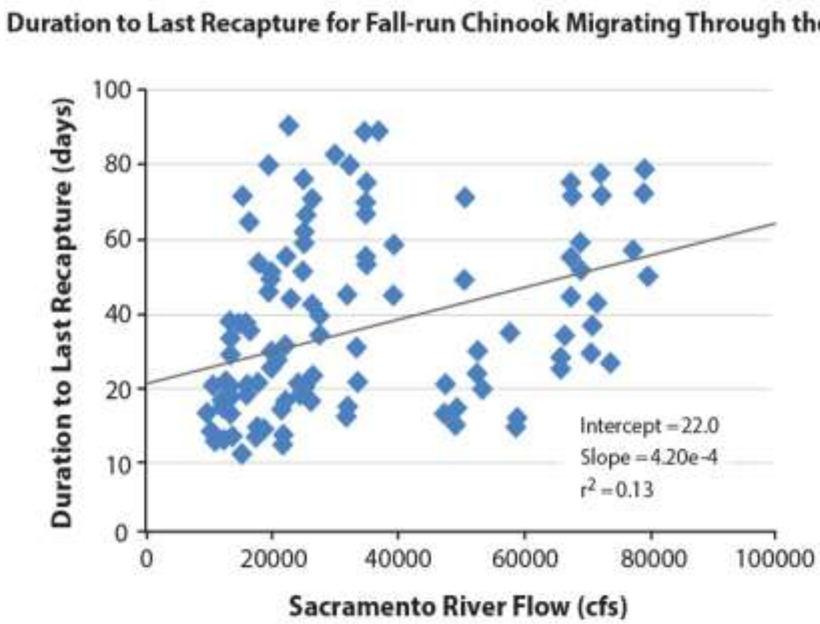

Figure 9-11. Relationship between average Sacramento River flow at Freeport over a 14-day period after release and the duration to last recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.

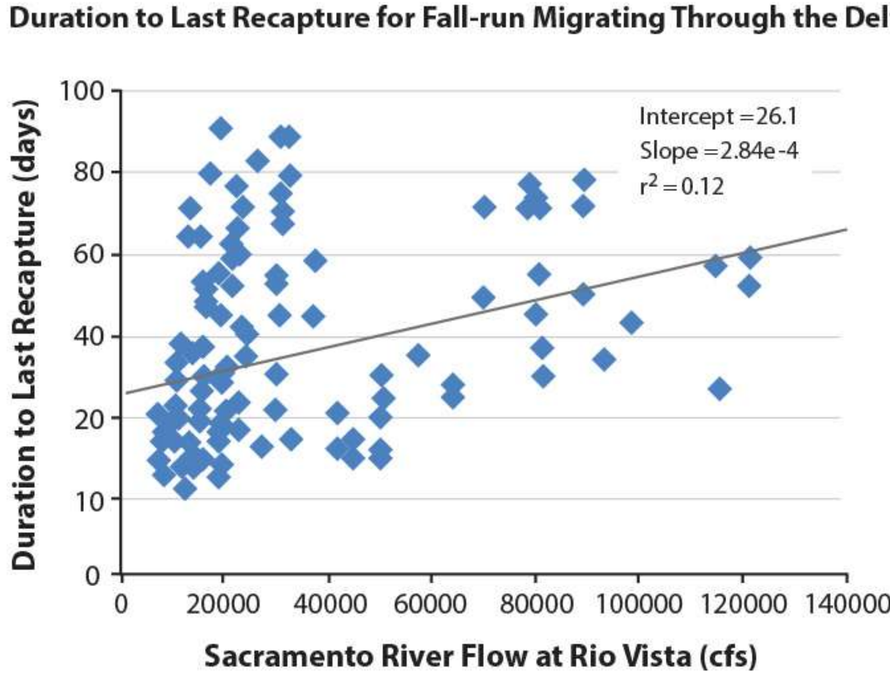

Figure 9-12. Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and the duration to last recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.

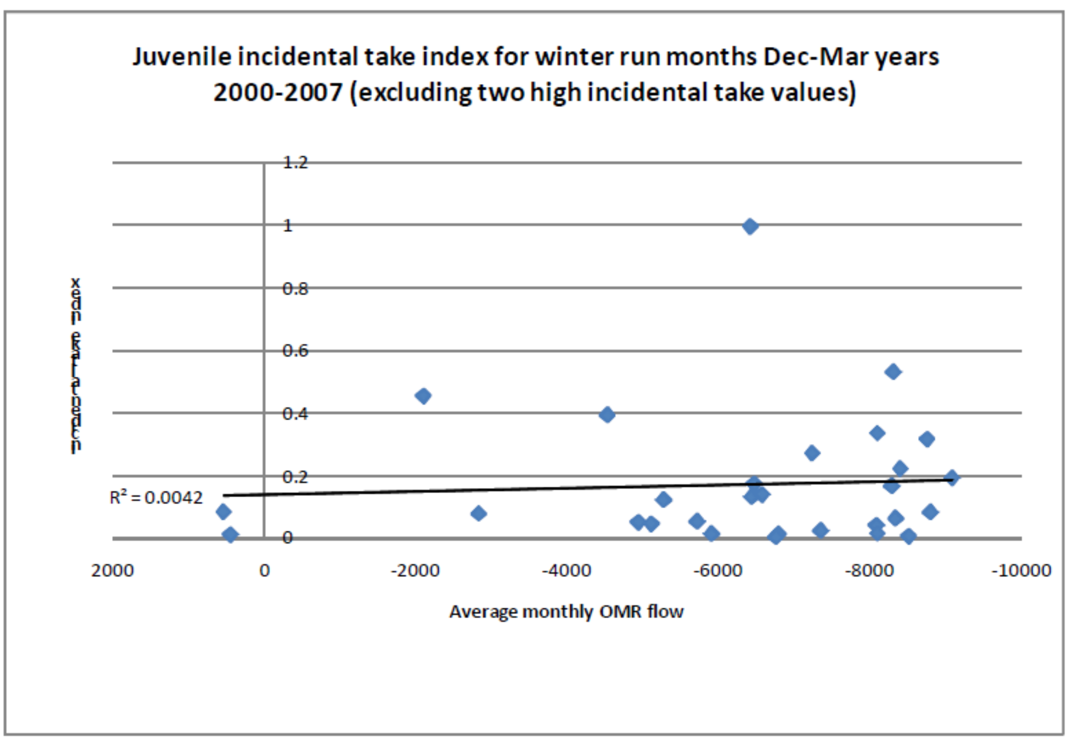

Figure 9-13. Relationship between OMR for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007 excluding two unusually high observations of salvage (Source: Deriso 2010).

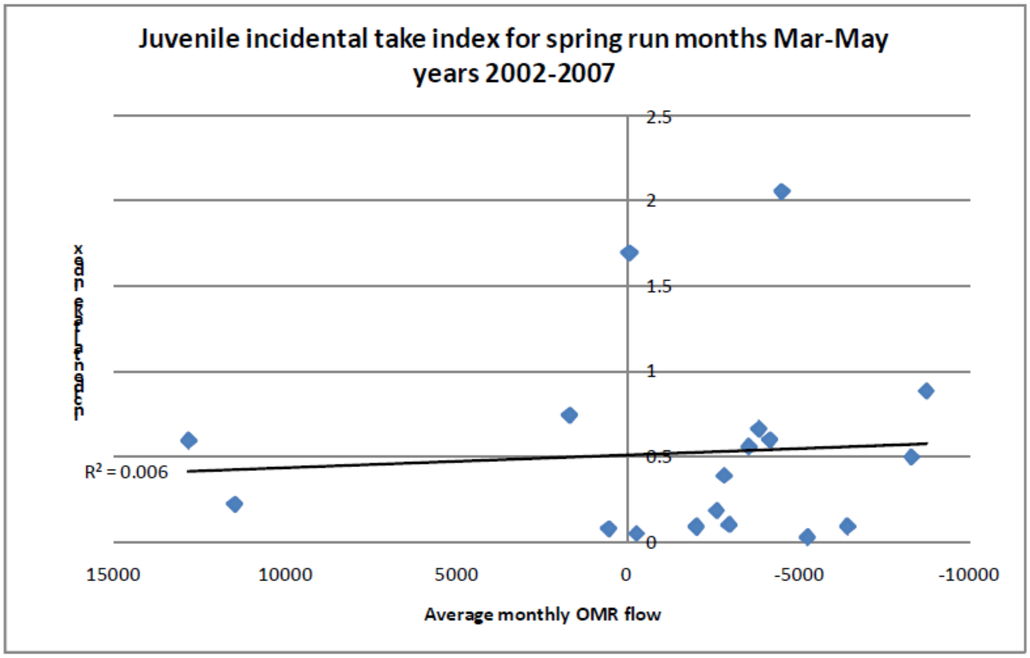

Figure 9-14. **Relationship between OMR for south Delta exports and salvage of juvenile spring-run Chinook salmon at the export facilities during March-May 2002-2007 (Source: Deriso 2010).**

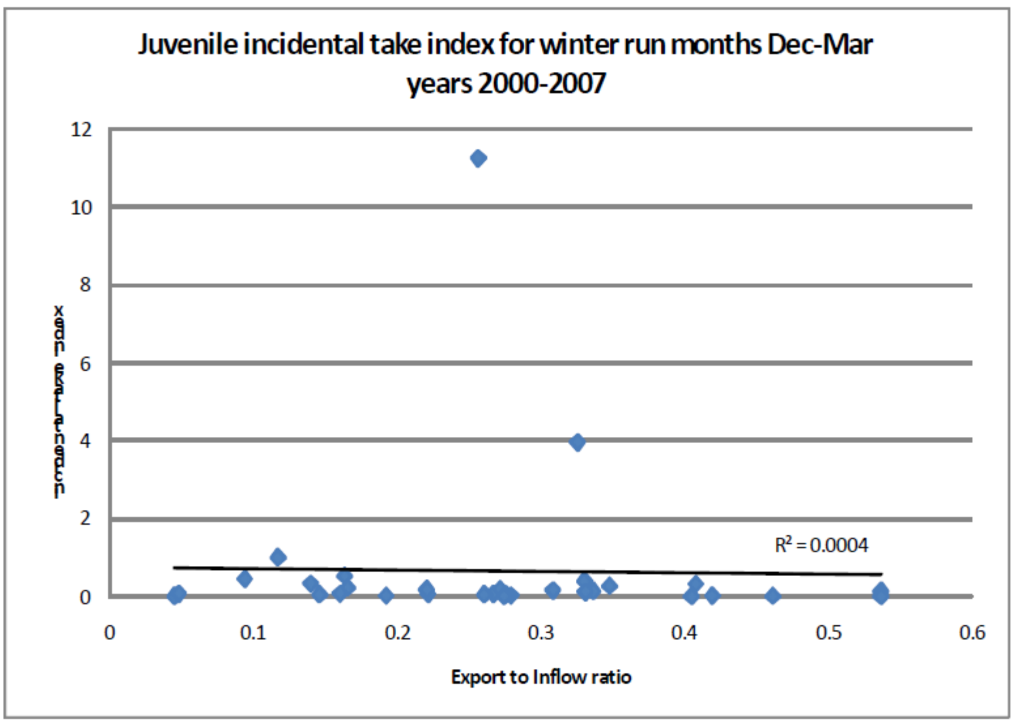

Figure 9-15. **Relationship between E:I ratio for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007, all data included (Source: Deriso 2010).**

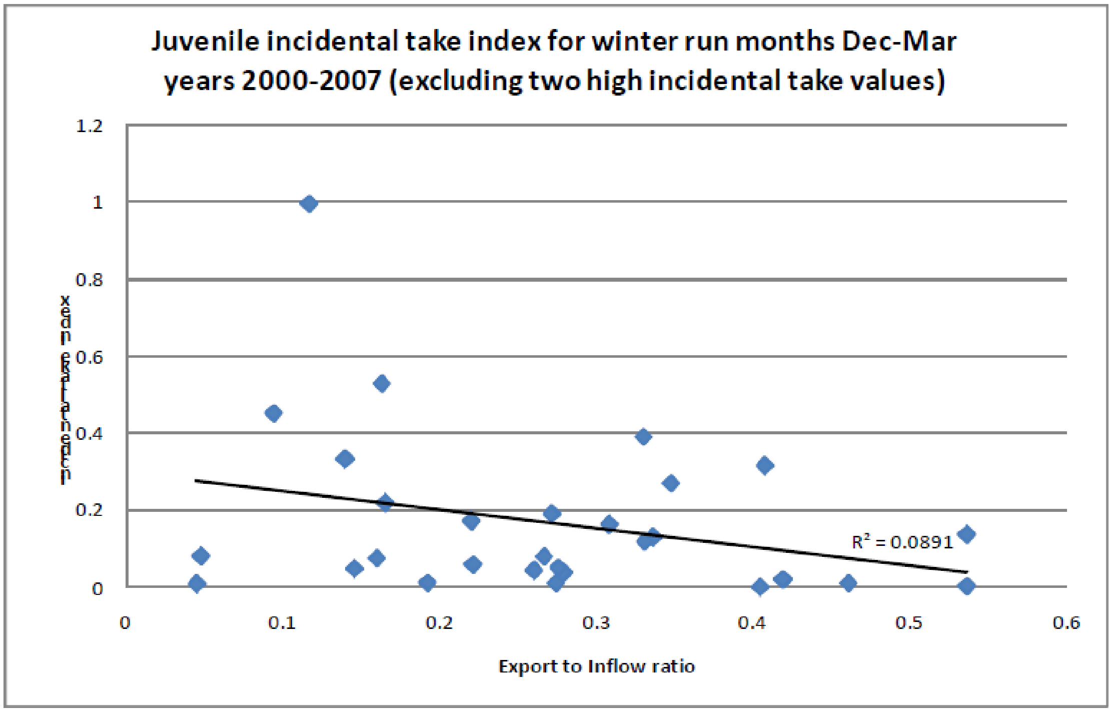

Figure 9-16. **Relationship between E:I ratio for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007 excluding two unusually high observations of salvage (Source: Deriso 2010).**

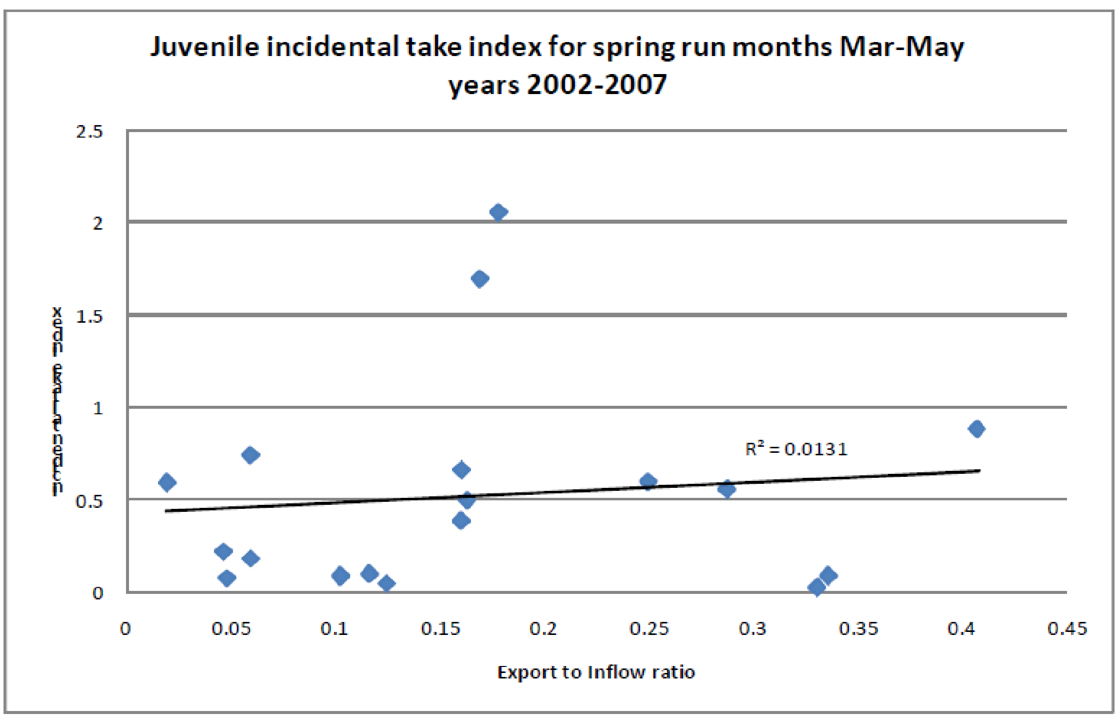

Figure 9-17. **Relationship between E:I ratio for south Delta exports and salvage of juvenile spring-run Chinook salmon at the export facilities during March-May 2002-2007 (Source: Deriso 2010).**

(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													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			
	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
			Delta[2]	89	113,920	0.00	0.03	0.41	0.00	0.00	0.02		10,138,880	3,042
			Delta[3]	21	94,442	0.00	0.36	1.43	0.00	0.51	1.44		1,983,282	17,255
		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
		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).

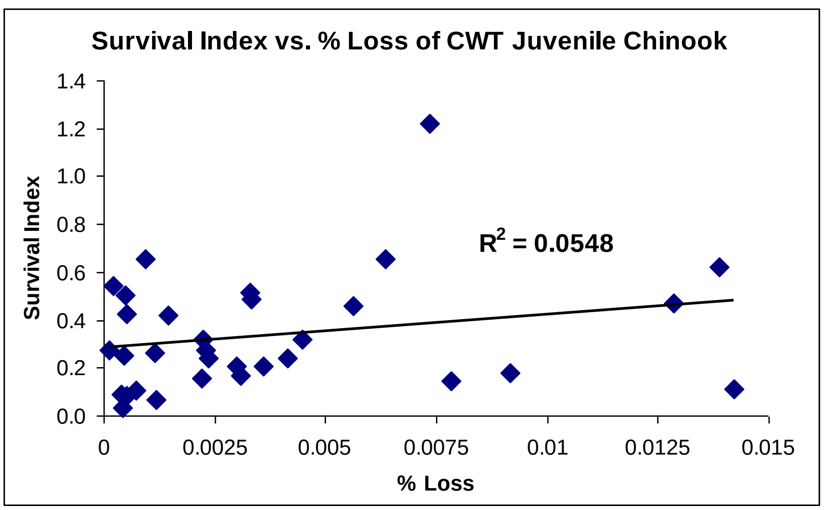

Figure 9-19. Relationship of Chinook smolt survival through the Delta to expanded percent loss of the same CWT groups at the CVP and SWP fish facilities. Data and survival estimates from Newman (2008) for late-fall CWT groups released during fall – winter in the Sacramento River Delta. The relationship 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.

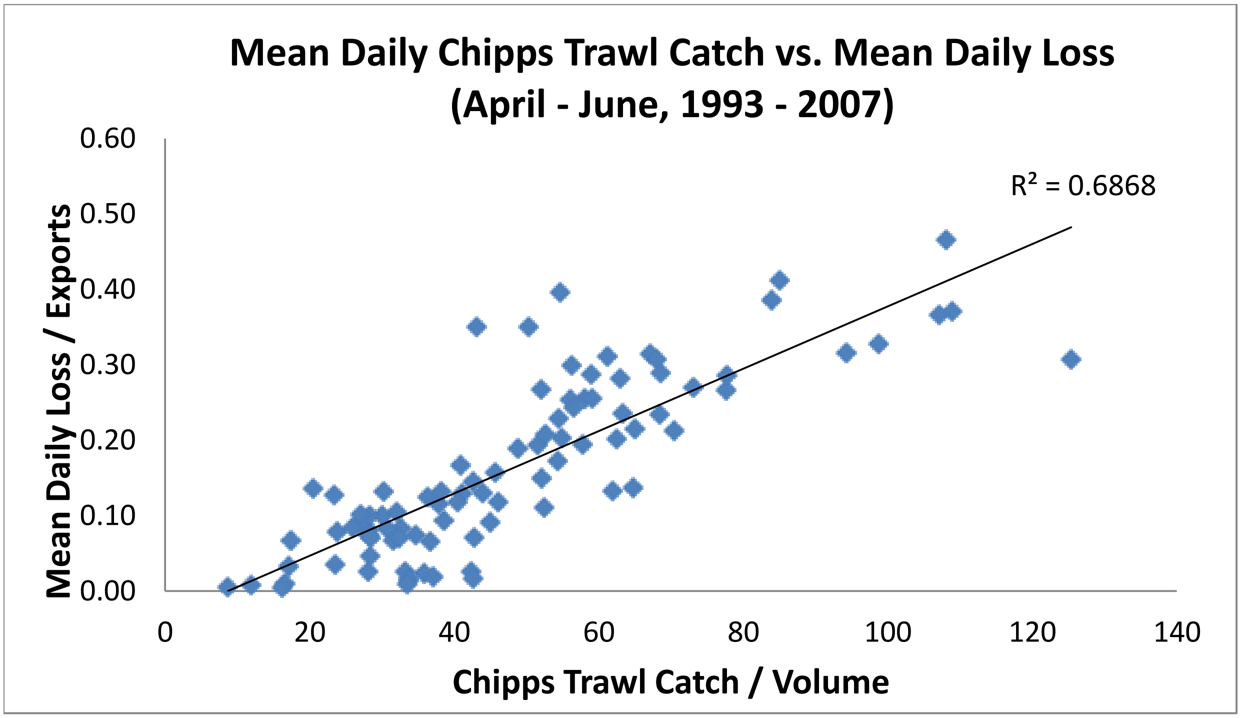

Figure 9-20. Correlation of expanded loss at the Delta pumps to the index of smolt abundance entering San Francisco Bay (Chipps Trawl catch/day). Each point is a monthly average across 1993-2007 for all juvenile Chinook combined. This demonstrates that catch at fish facilities reflects abundance of fish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

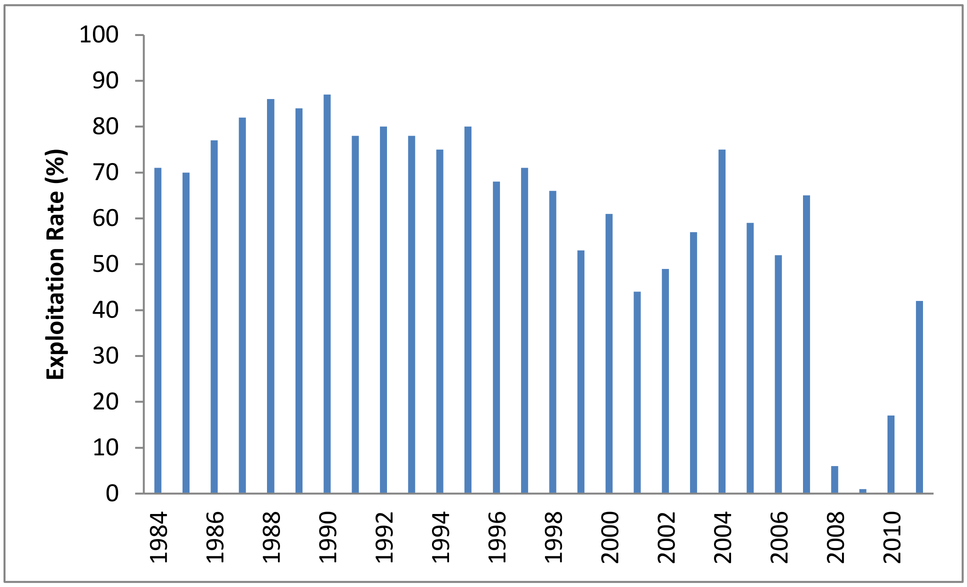

Figure 10-1. **Sacramento River fall-run Chinook salmon exploitation rates (Source: PMFC 2012).**

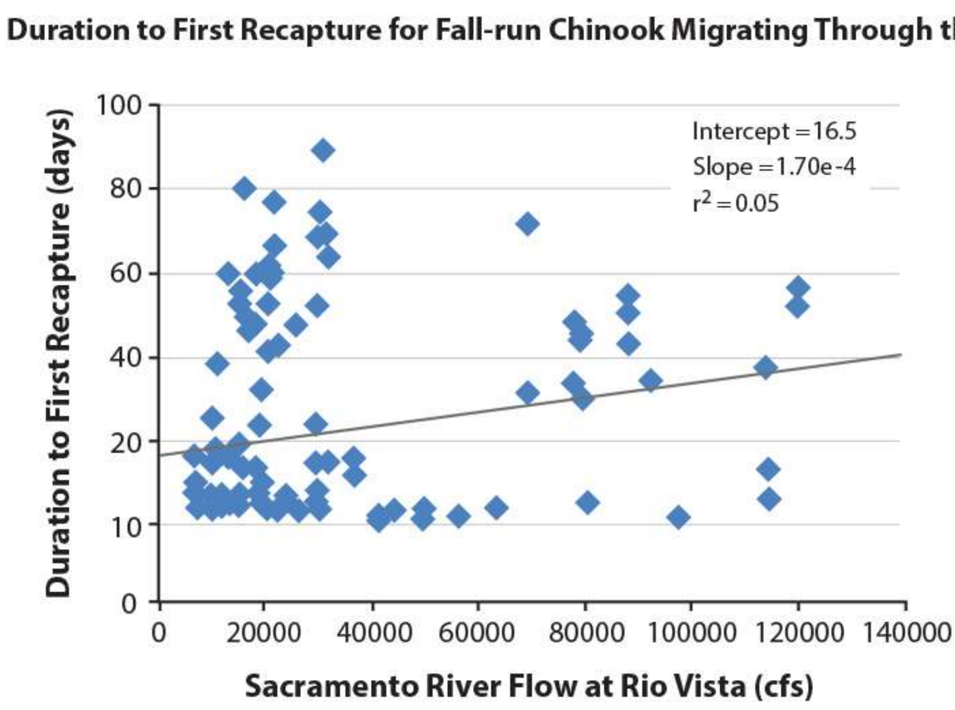

Figure 10-2. **The Sacramento Index (SI) and relative levels of its components. The Sacramento River fall Chinook escapement goal range of 122,000-180,000 adult spawners is noted on the vertical axis.**

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).

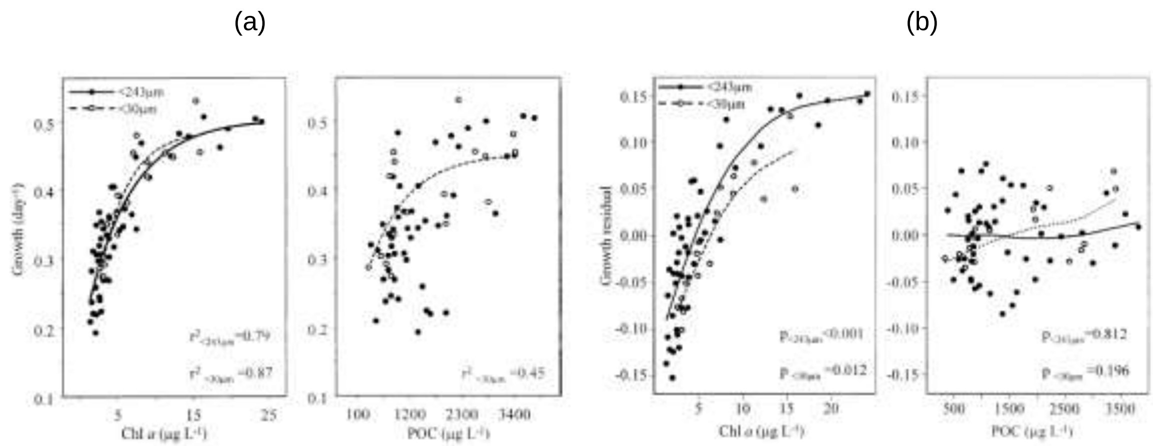

Figure A-1. Growth rate of *Daphnia* with algae and particulate organic carbon (POC). (a) Nonlinear regressions results of Daphnia growth rates against size fractionated Chl *a* and particulate organic carbon (POC). Growth rate is higher with algae (as measured by chlorophyll a concentrations) than with 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.

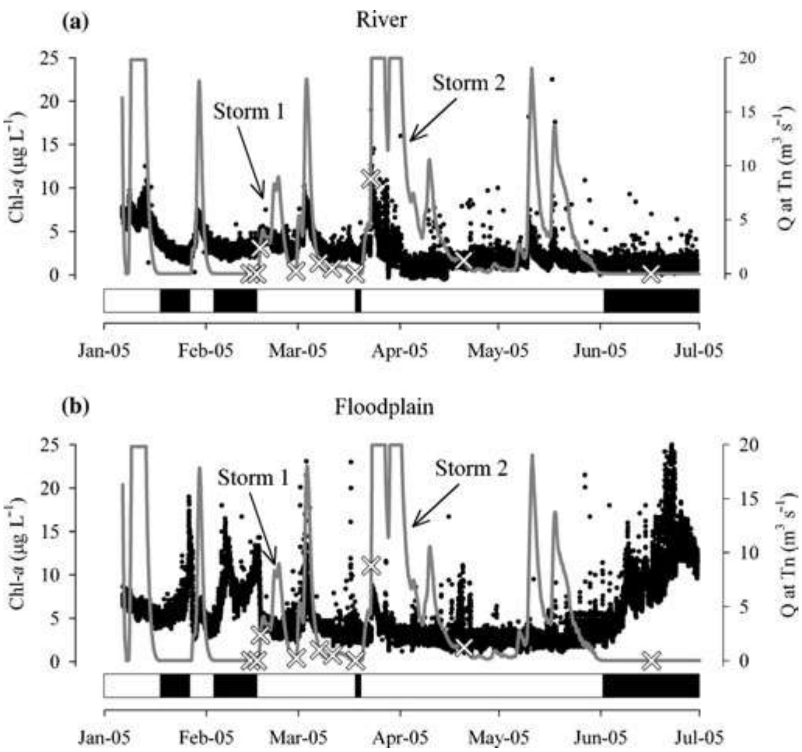

Figure A-2. Chlorophyll *a* (Chl *a*) concentration time series from (a) the river and (b) the floodplain pond at the Cosumnes River Preserve. Dates when Chl *a* distribution was measured are marked on the hydrograph with an "x". Black bars represent periods of disconnection with the river. The hydrograph 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.

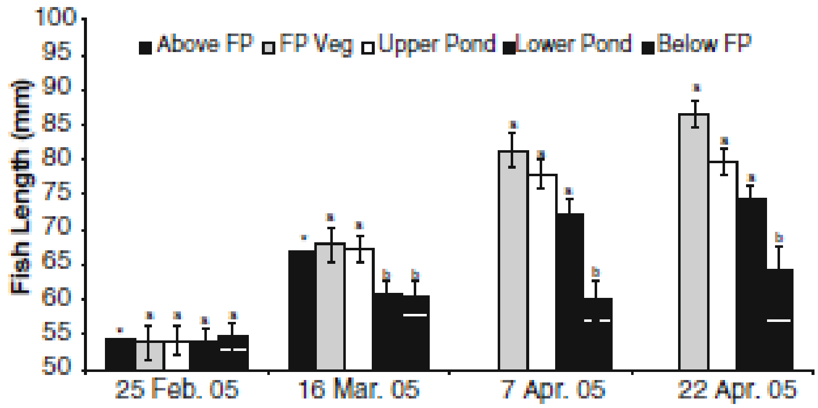

Figure A-4. Size (mean fork length ± standard error) of juvenile Chinook at the Cosumnes River Preserve reared in floodplain habitats (FP Veg, Upper Pond, and Lower Pond) and river channel sites (Above FP and Below FP) over four sampling sessions during the 2005 flood season. Habitats with different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

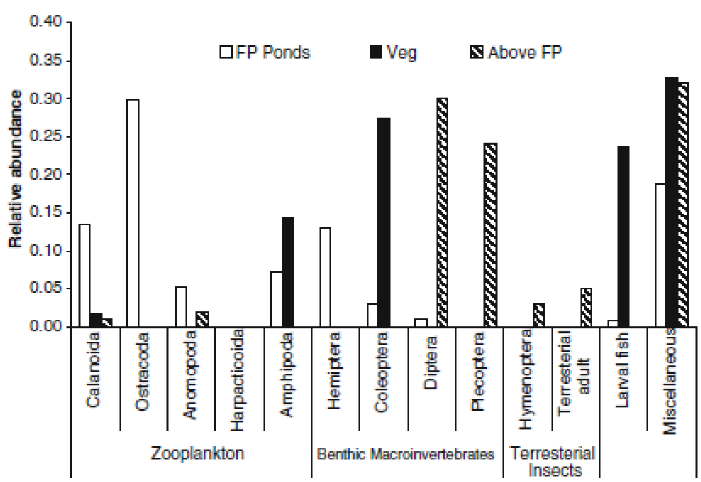

Figure A-5. Relative abundance of prey items in juvenile Chinook salmon on the Cosumnes River (1) floodplain ponds, (2) floodplain vegetation, and (3) river channel above (upstream) from the floodplain. From Jeffres *et al.* 2008.

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.

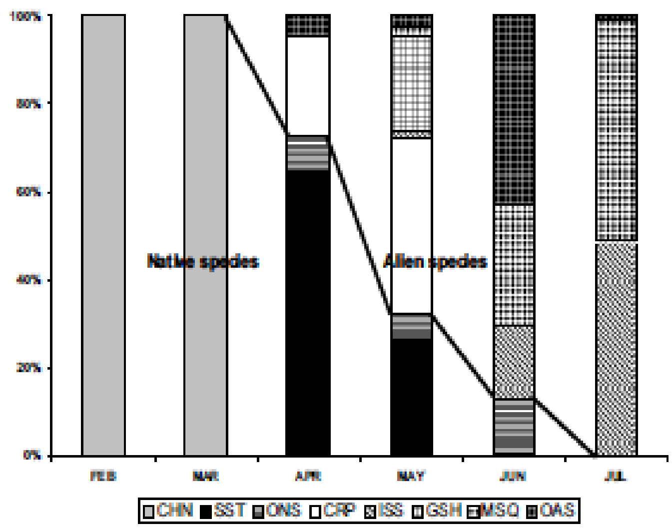

Figure A-6. **Monthly percent abundance of juvenile fishes on the Cosumnes River floodplain for the year 2000. The line connects the dividing line between native and non-native (alien) species. Native fish were predominant early in the season. CHN = Chinook salmon, SST = splittail, ONS = other native 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^{o}F, April 1 – Sept. 30; <60 ^{o}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^{o}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

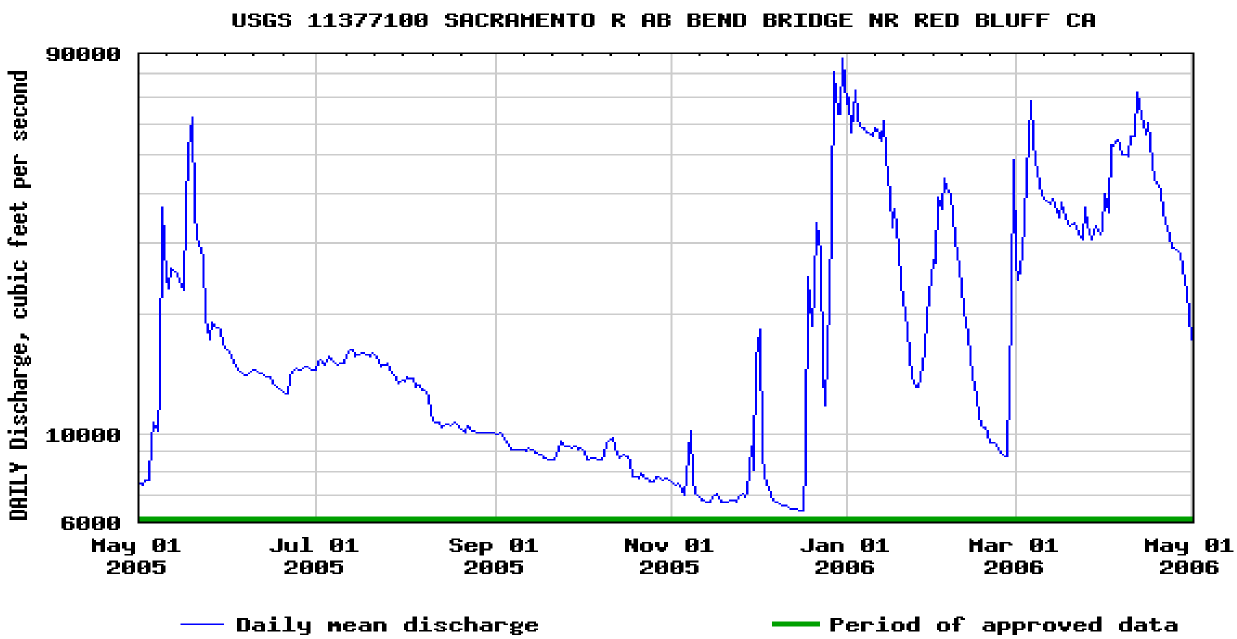

Figure C-1. Daily flows on the Sacramento River at Red Bluff Diversion Dam from May 1, 2005-May 1, 2006(Source: USGS).

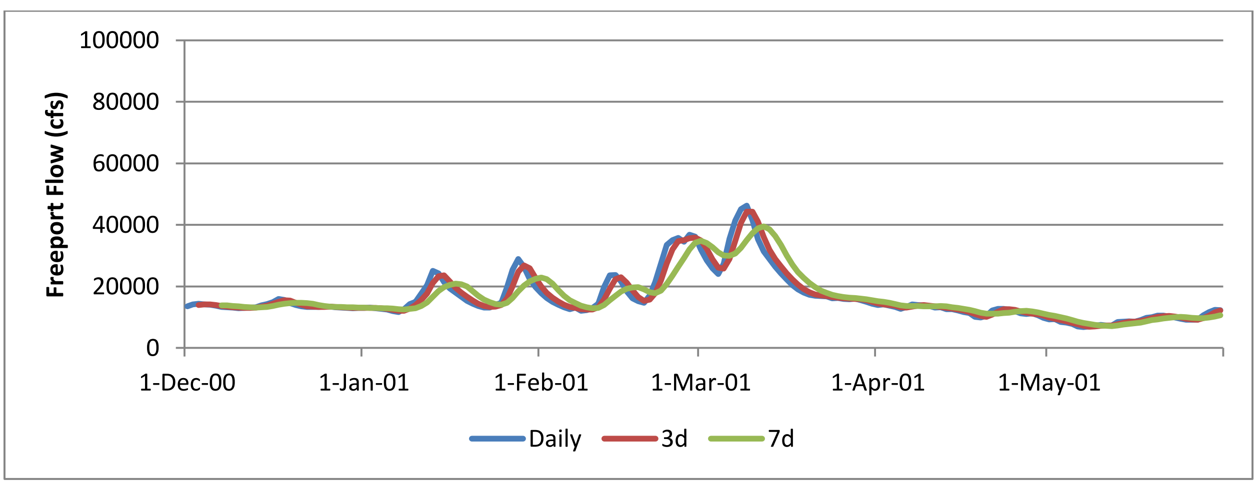

Figure C-2. Daily flow in the Sacramento River at Freeport - 2001(Source: DWR DAYFLOW).

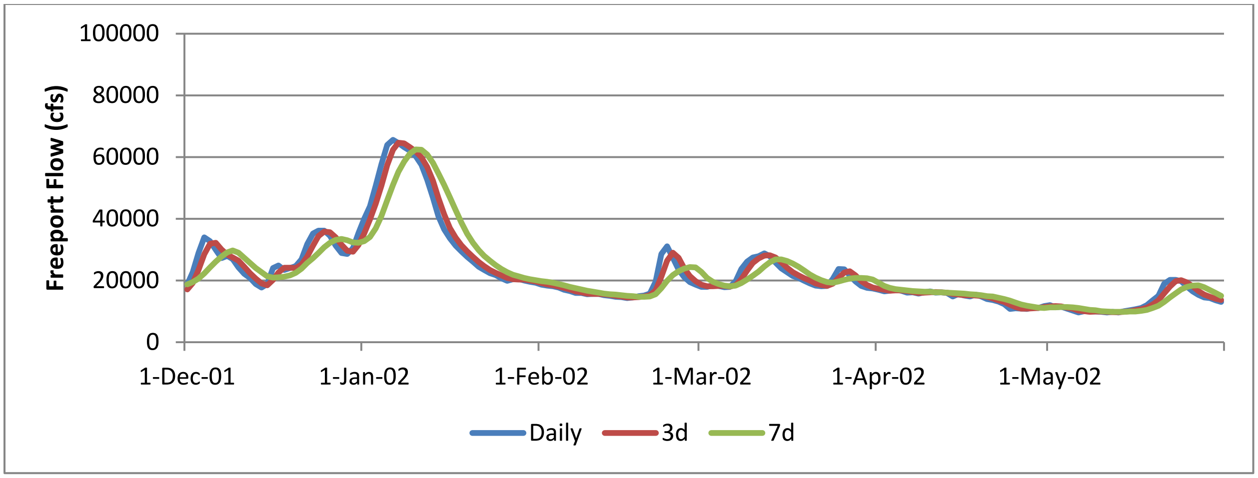

Figure C-3. Daily flow in the Sacramento River at Freeport – 2002 (Source: DWR DAYFLOW).

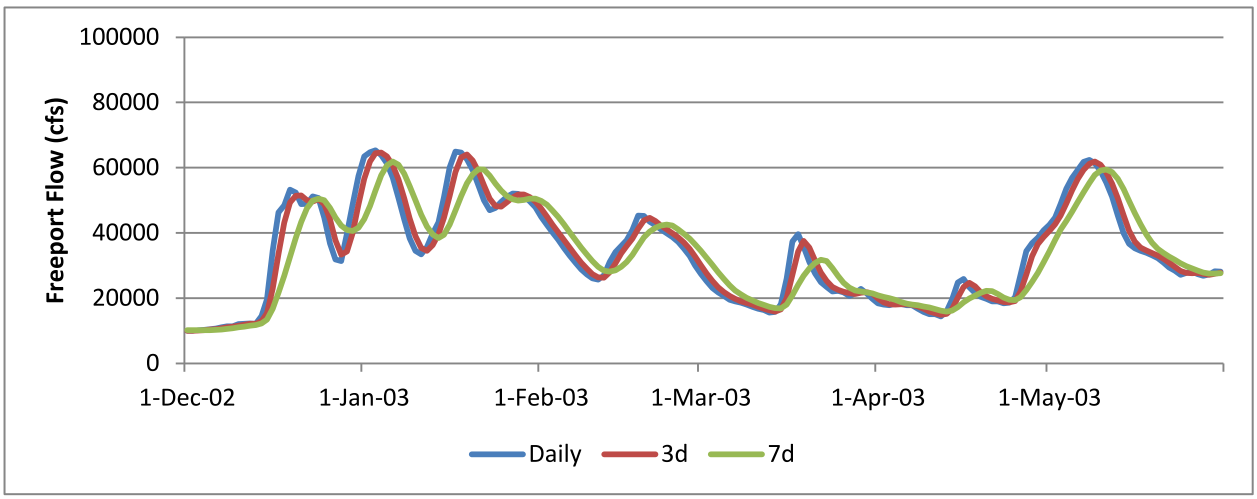

Figure C-4. Daily flow in the Sacramento River at Freeport – 2003 (Source: DWR DAYFLOW).

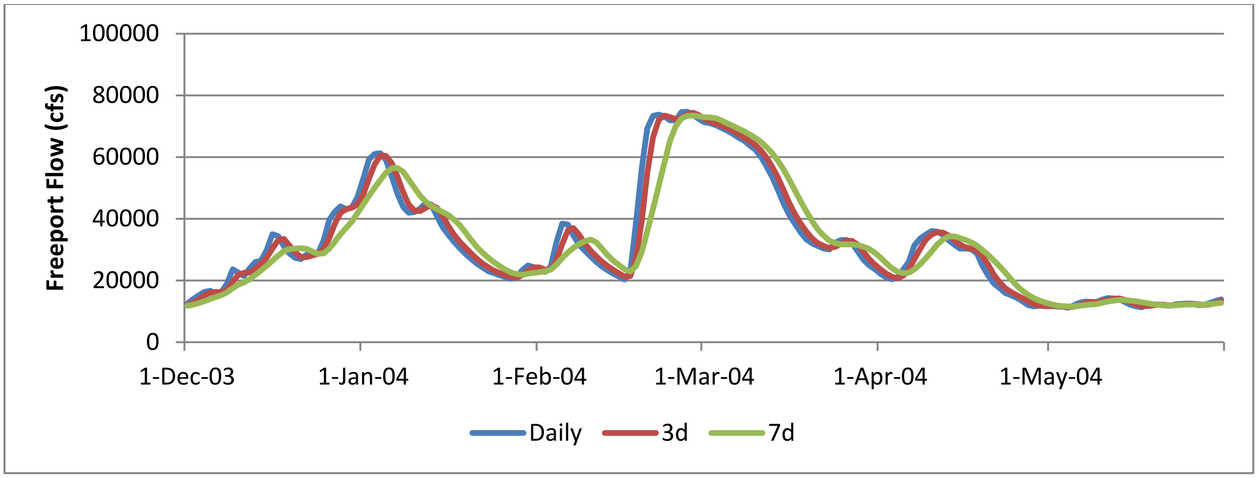

Figure C-5. Daily flow in the Sacramento River at Freeport – 2004 (Source: DWR DAYFLOW).

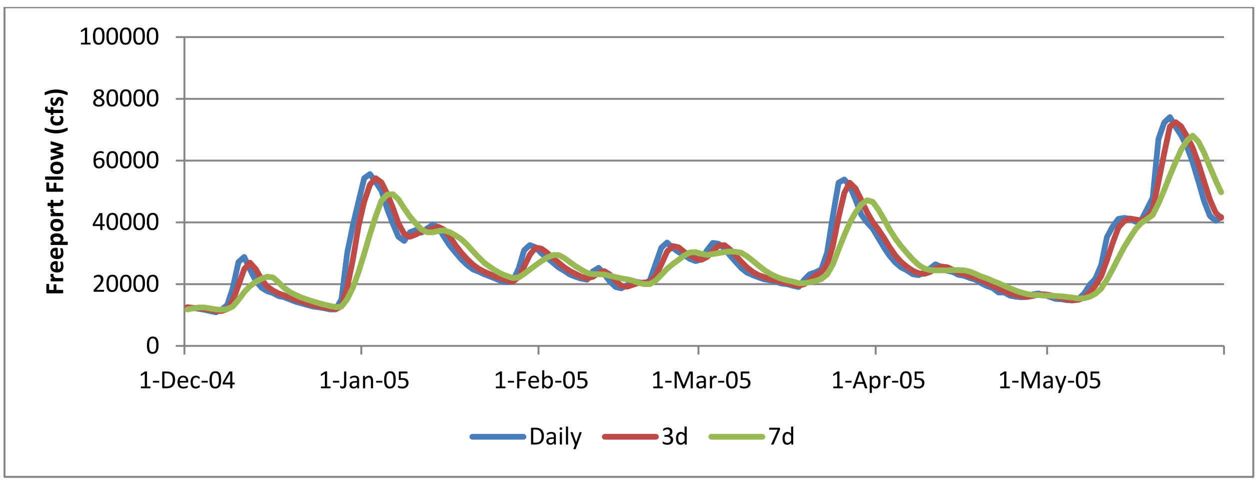

Figure C-6. Daily flow in the Sacramento River at Freeport - 2005 (Source: DWR DAYFLOW).

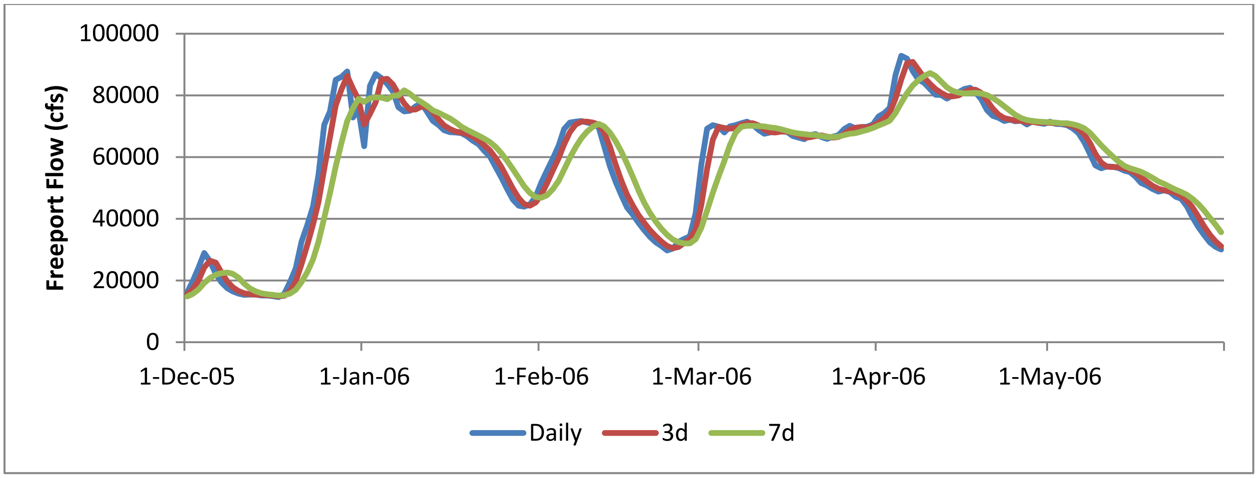

Figure C-7. Daily flow in the Sacramento River at Freeport - 2006 (Source: DWR DAYFLOW).

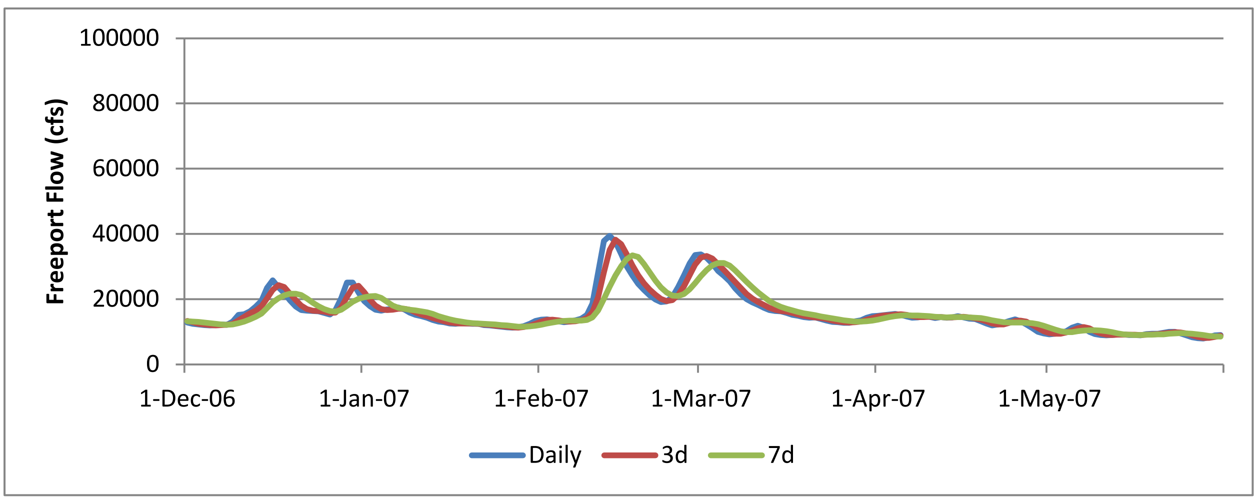

Figure C-8. Daily flow in the Sacramento River at Freeport - 2007 (Source: DWR DAYFLOW).

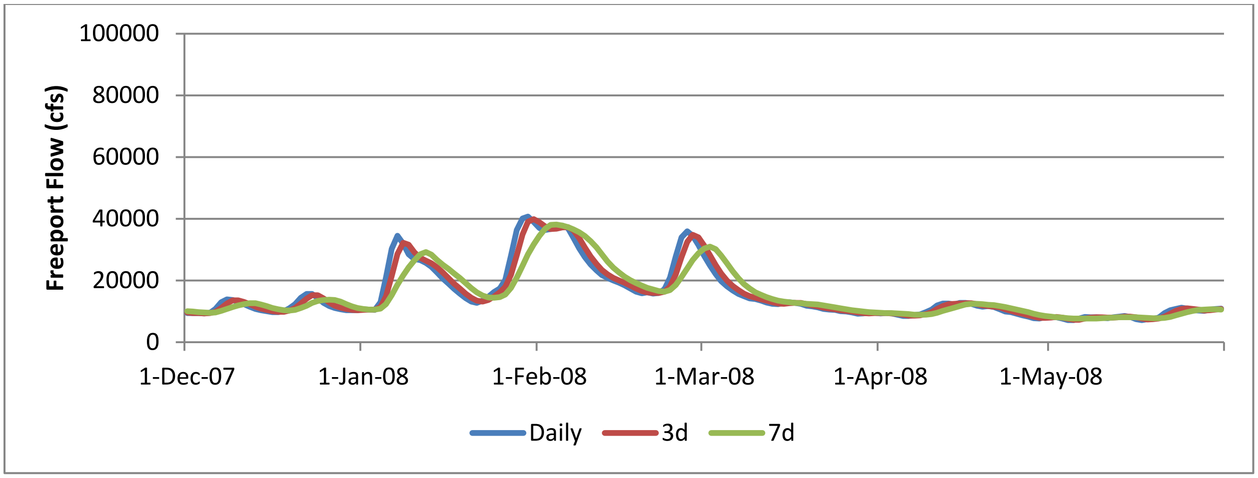

Figure C-9. Daily flow in the Sacramento River at Freeport - 2008 (Source: DWR DAYFLOW).

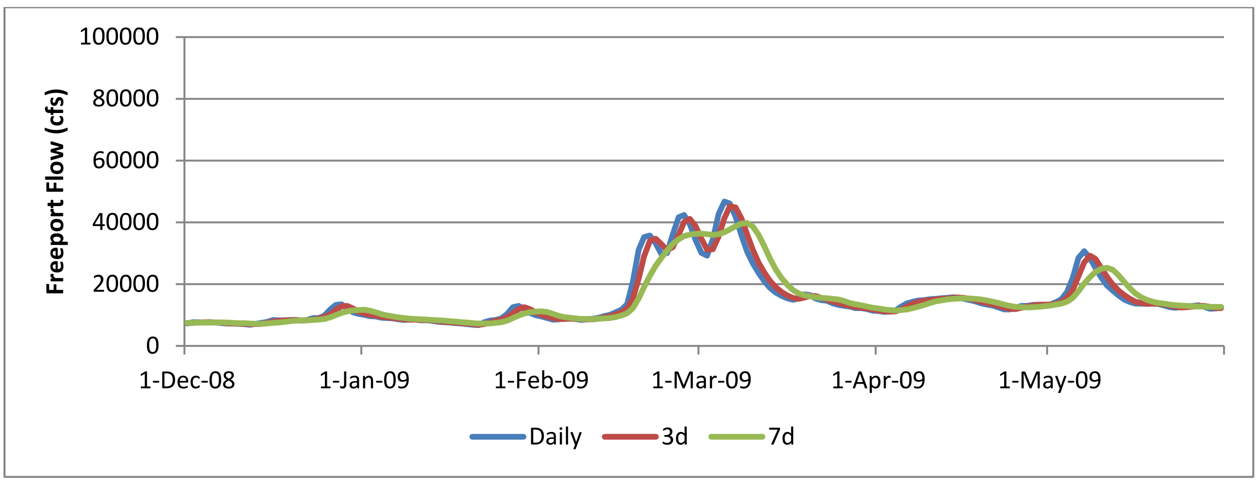

Figure C-10. Daily flow in the Sacramento River at Freeport - 2009 (Source: DWR DAYFLOW).

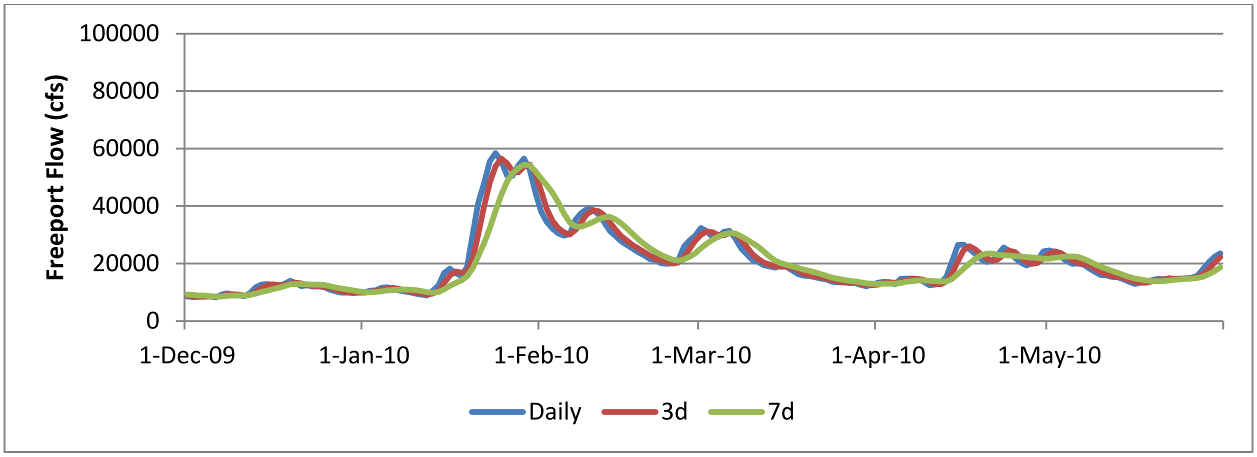

Figure C-11. Daily flow in the Sacramento River at Freeport - 2010 (Source: DWR DAYFLOW).

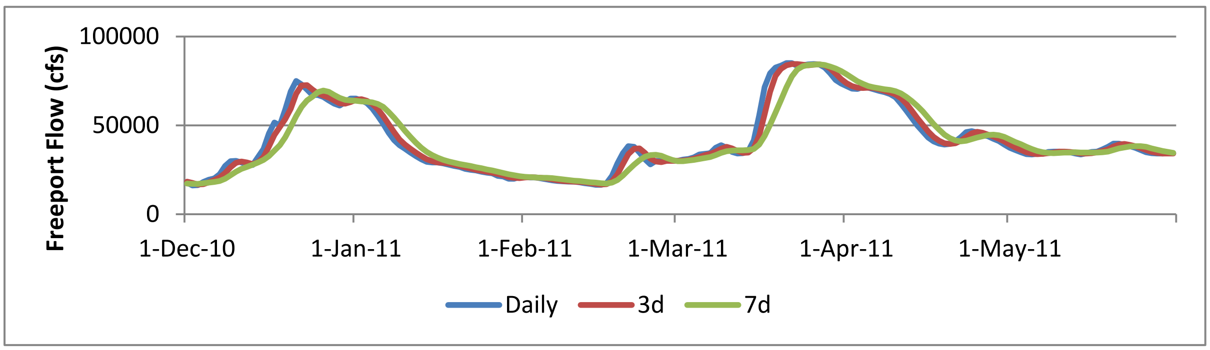

Figure C-12. Daily flow in the Sacramento River at Freeport - 2011 (Source: DWR DAYFLOW).

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
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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.
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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
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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?
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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
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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
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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
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glibert_etal_2006.pdf	Escalating worldwide use of urea – a global change contributing to coastal eutrophication
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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
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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
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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
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lam_etal_2008.pdf	Modeling seasonal distribution of pelagic marine fishes and squids. In Cheung et al.
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strayer_etal_cjfas_2004.pdf	Effects of an invasive bivalve (Dresseina polymorpha) on fish in the Hudson River estuary
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swanson_etal_2000.pdf	Comparative environmental tolerances of threatened delta smelt (Hypomesus transpacificus) and introduced wakasagi (H. nipponensis) in an altered California estuary
sweetnam_1999.pdf	Status of delta smelt in the Sacramento-San Joaquin estuary
thomson_etal_2010.pdf	Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary
tbi_1998.pdf	From the Sierra to the Sea The Ecological History of the San Francisco Bay-Delta Watershed

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ucd_2012.pdf	2011 delta smelt predation project update
ucd_2009.pdf	Pharmaceuticals and personal care products in surface water - Occurrence, fate and transport, and effect on aquatic organisms
uhlen_2008.pdf	Affinity as a tool in life science
usbr_2011.pdf	Adaptive management of fall outflow for delta smelt protection and water supply reliability, milestone draft
usfws_1995.pdf	Recovery plan for the Sacramento-San Joaquin Delta native fishes
usfws_1996.pdf	Recovery plan for the Sacramento-San Joaquin Delta native fishes
usfws_2008.pdf	Delta smelt biological opinion on the coordinated operations of the Central Valley Project and State Water Project
usfws_fr_2010.pdf	Endangered and Threatened Wildlife and Plants; 12-month finding on a petition to list the Sacramento splittail as endangered or threatened. 50 CFR Part 17, Docket No. FWS-R8-ES-2010-0013
usfws_2012.pdf	Notice of 12-month petition finding
vangeen_luoma_1999.pdf	The impact of human activities on sediments of San Francisco Bay, California: An overview
vannieuwenhuyse_2007.pdf	Response of summer chlorophyll concentration to reduced phosphorus concentration in the Rhine River (Netherlands) and the Sacramento-San Joaquin Delta (California, USA).
wagner_etal_2011.pdf	Statistical models of temperature in the Sacramento-San Joaquin Delta under climate-change scenarios and ecological implications
wang_iep_1986.pdf	Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories
wanger_2011.pdf	Findings of fact and conclusions of law re. plaintiffs' request or injunctive relief against implementation of RPA component 3 (Action 4) (Doc. 1013).
weiland_murphy _2010.pdf	The route to best science in implementation of the Endangered Species Act’s consultation mandate: the benefits of structured effects analysis
wenger_2008.pdf	Use of surrogates to predict the stressor response of imperiled species
weston_lydy_2010.pdf	Urban and agricultural sources of pyrethroid insecticides to the Sacramento-San Joaquin Delta of California
winder _Jassby_2010.pdf	Shifts in zooplankton community structure: Implications for food web processes in the upper San Francisco estuary
wright_schoellha_2004.pdf	Trends in the sediment yield of the Sacramento River, California, 1957-2001
wrightwalt_volz_2009.pdf	Municipal wastewater concentrations of pharmaceutical and xeno-estrogens: Wildlife and human health implications
young_cech_1996.pdf	Environmental tolerances and requirements of splittail

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ahearn_et_al._2006.pdf	Priming the productivity pump: flood pulse driven trends in suspended algal biomass distribution across a restored floodplain.
baker_morhardt_2001.pdf	Survival of Chinook Salmon Smolts in the Sacramento-San Joaquin Delta and Pacific Ocean
bartholow_2004.pdf	Modeling Chinook Salmon with SALMOD on the Sacramento River, California
bartholow_et_al_1997.pdf	SALMOD - A Population Model For Salmonids USER'S MANUAL Beta Test Version 2.0 December, 1997
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bdcp_2010.pdf	Effects analysis
beamish_mahnken_2001.pdf	A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change
bjornn_and_reiser_1991.pdf	Habitat Requirements of Salmonids in Streams
blake_et_al_2012.pdf	Th-2,3-18 Outmigration Behavior of Juvenile Chinook Salmon in a River Bend in the Sacramento River At Clarksburg California
boles_1998.pdf	Water temperature effects on Chinook salmon (*Oncorhynchus tshawytscha*) with emphasis on the Sacramento River - a literature review
booth_et_al_2006.pdf	Hydrologic variability of the Cosumnes River floodplain
bottom_et_al_2011.pdf	Estuarine Habitat and Juvenile Salmon: Current and Historical Linkages in the Lower Columbia River and Estuary
bowen_et_al_2009.pdf	2009 Effectiveness of a Non-Physical Fish Barrier at the Divergence of the Old and San Joaquin Rivers (CA)
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cdfg_2010.pdf	Flows Needed in the Delta to Restore Anadromous Salmonid Passage from the San Joaquin River at Vernalis to Chipps Island
cloern_2007.pdf	Habitat connectivity and ecosystem productivity: implications from a simple model
conrad_et_al_2010a.pdf	Rising abundance of largemouth bass in the littoral zone of Sacramento –San Joaquin Delta: the role of *Egeria densa*
conrad_et_al_2010b.pdf	More big bass: Understanding the role of largemouth bass as top predators in the littoral zone
conrad_et_al_2011.pdf	Invaders Helping Invaders: Expansion of Largemouth Bass in the Sacramento-San Joaquin Delta Facilitated by Brazilian Waterweed, *Egeria Densa*
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deas_lowney_2000.pdf	Water Temperature Modeling Review Central Valley September 2000
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feyrer_healey_2003.pdf	Fish community structure and environmental correlates in the highly altered southern Sacramento-San Joaquin Delta
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grosholz_gallo_2006.pdf	The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain
hansen_et_al_1994.pdf	The size ratio between planktonic predators and their prey
hrsc_2012.pdf	California Hatchery Review Report
jager_rose_2003.pdf	Designing Optimal Flow Patterns for Fall Chinook Salmon in a Central Valley, California, River
jassby_et_al_2002.pdf	Annual primary production: patterns and mechanisms of change in a nutrient rich tidal ecosystem
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junk_et_al_1989.pdf	The flood pulse concept in river-floodplain systems
kimmerer_2008.pdf	Losses of Sacramento River Chinook Salmon and Delta Smelt to Entrainment in Water Diversions in the Sacramento-San Joaquin Delta
kondolf_et_al_2006_.pdf	Process-based ecological river restoration: visualizing three-dimensional connectivity and dynamic vectors to recover lost linkages
lehman_et_al_2008.pdf	The influence of floodplain habitat on the quantity of riverine phytoplankton carbon produced during the flood season in San Francisco Estuary
levin_1992.pdf	Orchestrating Environmental Research and Assessment
lewis_et_al_2001.pdf	Food web analysis of the Orinoco floodplain based on production estimates and stable isotope data
lindley_et_al_2009.pdf	What caused the Sacramento River fall Chinook stock collapse?
lopez_et_al_2006.pdf	Ecological values of shallow-water habitats: implications for the restoration of disturbed ecosystems
lund_et_al_2007.pdf	Envisioning Futures for the Sacramento-San Joaquin Delta
macfarlanenorton2002.pdf	Physiological ecology of juvenile chinook salmon (*Oncorhynchus tshawytscha*) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California
mahoney_rood_1998.pdf	Streamflow requirements for cottonwood seedling recruitment: an integrative model
mcEwan_2001.pdf	Central Valley Steelhead
mcewan_jackson_1996.pdf	Steelhead restoration and management plan for California
michel_2010.pdf	RIVER AND ESTUARINE SURVIVAL AND MIGRATION OF YEARLING SACRAMENTO RIVER CHINOOK SALMON (*ONCORHYNCHUS TSHAWYTSCHA*) SMOLTS AND THE INFLUENCE OF ENVIRONMENT
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newman_lindley_2006.pdf	Accounting for demographic and environmental stochasticity, observation error and parameter uncertainty in fish population dynamics models
newman_rice_2002.pdf	Modeling the Survival of Chinook Salmon Smolts Outmigrating Through the Lower Sacramento River System
nmfs_1996.pdf	Factors for Decline A Supplement to the Notice of Determination for West Coast Steelhead Under the Endangered Species Act
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nmfs_2010.pdf	ENDANGERED SPECIES ACT SECTION 7 CONSULTATION BIOLOGICAL OPINION
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rood_et_al_2005.pdf	Managing river flows to restore floodplain forests
rose_et_al_2011.pdf	Salmonid Integrated Life Cycle Models Workshop
ruckelshaus_2002.pdf	THE PACIFIC SALMON WARS: What Science Brings to the Challenge of Recovering Species
scheuerell_et_al.pdf	The Shiraz Model: A tool for incorporating anthrogogenic effects and fish hbitat relationships in conservatin planning
schramm_eggleton2006.pdf	Applicability of the flood-pulse concept in a temperate floodplain river ecosystem: Thermal and temporal components
smith_et_al_2002.pdf	Factors Associated with Travel Time and Survival of Migrant Yearling Chinook Salmon and Steelhead in the Lower Snake River
sjrga_2006.pdf	San Joaquin River Agreement 2006 Annual Technical Report
sjrga_2008.pdf	San Joaquin River Agreement Vernalis Adaptive Management Plan 2008 Annual Technical Report
sjrga_2010.pdf	San Joaquin River Agreement 2009 Annual Technical Report
sommer_et_al._2004.pdf	Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA
sommer_et_al._2005.pdf	Habitat use and stranding risk of juvenile Chinook salmon on a seasonal floodplain
sommer_et_al._2008.pdf	Habitat associations and behavior of adult and juvenile splittail (Cyprinidae: *Pogonichthys macrolepidotus*) in a managed seasonal floodplain wetland
sommer_et_al_1997.pdf	Resilience of Splittail in the Sacramento-San Joaquin Estuary.
sommer_et_al_2001a.pdf	Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival
sommer_et_al_2001b.pdf	California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture
sommer_et_al_2005.pdf	Habitat use and stranding risk of juvenile Chinook salmon on a seasonal floodplain
stillwater_2009.pdf	Lower Tuolumne River Instream Flow Studies Final Study Plan
swenson_et_al._2003.pdf	Restoring floods to floodplains: riparian and floodplain restoration at the Cosumnes River Preserve
swrcb_flow_crt_2010.pdf	Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem Prepared Pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009
tockner_et_al._2000.pdf	An extension of the flood pulse concept
tockner_stanford_2002.pdf	Riverine floodplains: present state and future trends
usbr_2009.pdf	Additional comments on the draft NMFS biological opinion on CVP and SWP on salmonids and sturgeon
usfws_1986.pdf	Species Profiles: Lit e Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) CHINOOK SALMON
usfws_1996.pdf	Identification of the Instream Flow Requirements for Steelhead and Fall-run Chinook Salmon Spawning in the Lower American River
usfws_2005.pdf	Flow-habitat relationships for Chinook Salmon rearing in the Sacramento River between Keswick Dam and Battle Creek
usfws_2011.pdf	IDENTIFICATION OF THE INSTREAM FLOW REQUIREMENTS FOR ANADROMOUS FISH IN THE STREAMS WITHIN THE CENTRAL VALLEY OF CALIFORNIA AND FISHERIES INVESTIGATIONS
vogel_2011.pdf	Insights into the Problems, Progress, and Potential Solutions for Sacramento River Basin Native Anadromous Fish Restoration
ward_2002.pdf	Inundation dynamics in braided floodplains
wiens_et_al_undated.pdf	Using surraogate species and groups for conservation planning and management
wells_et_al_2008.pdf	Relationships between oceanic conditions and growth of Chinook salmon (*Oncorhynchus tshawytscha*) from California, Washington, and Alaska, USA
williams_2006.pdf	Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California
williams_et_al._2009.pdf	Quantifying activated floodplains on a lowland regulated river: its application to floodplain restoration in the Sacramento Valley
wood_et_al._2006.pdf	Overview of Cosumnes riparian bird study and recommendations for monitoring and management
yoshiyama_et_al_1998.pdf	Historical Abundance and Decline of Chinook Salmon in the Central Valley Region of California
zeug_et_al_2012.pdf	Application of a Life Cycle Simulation Model to Evaluate Impacts of Water Management and Conservation Actions on an Endangered Population of Chinook Salmon

Fisheries Resources: A Technical Assessment of Available Scientific Information

State Water Resources Control Board
Phase II Comprehensive Review of the Bay-Delta Plan

Workshop 2: Fisheries Resources

October 1-3, 2012

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

Review: Ecological Change

- Food Web
- Physical Landscape
- Water Temperature
- Turbidity
- Changes in Water Flows

The Management Challenge

Today's Science Presentation

- **Salmon**
- Pelagic Fish

Salmon Presentation Outline

- Relationships between flow and salmon survival
  - Dr. Chuck Hanson
- Integration of scientific information and decisionmaking
  - Steve Cramer

Next up:

Dr. Chuck Hanson, Hanson Environmental

Dr. Steve Cramer, Cramer Fish Sciences

Salmon technical presentation

Fisheries Resources: A Technical Assessment of Available Scientific Information Regarding Salmonids

State Water Resources Control Board

Phase II Comprehensive Review of the Bay-Delta Plan

Workshop 2: Fisheries Resources

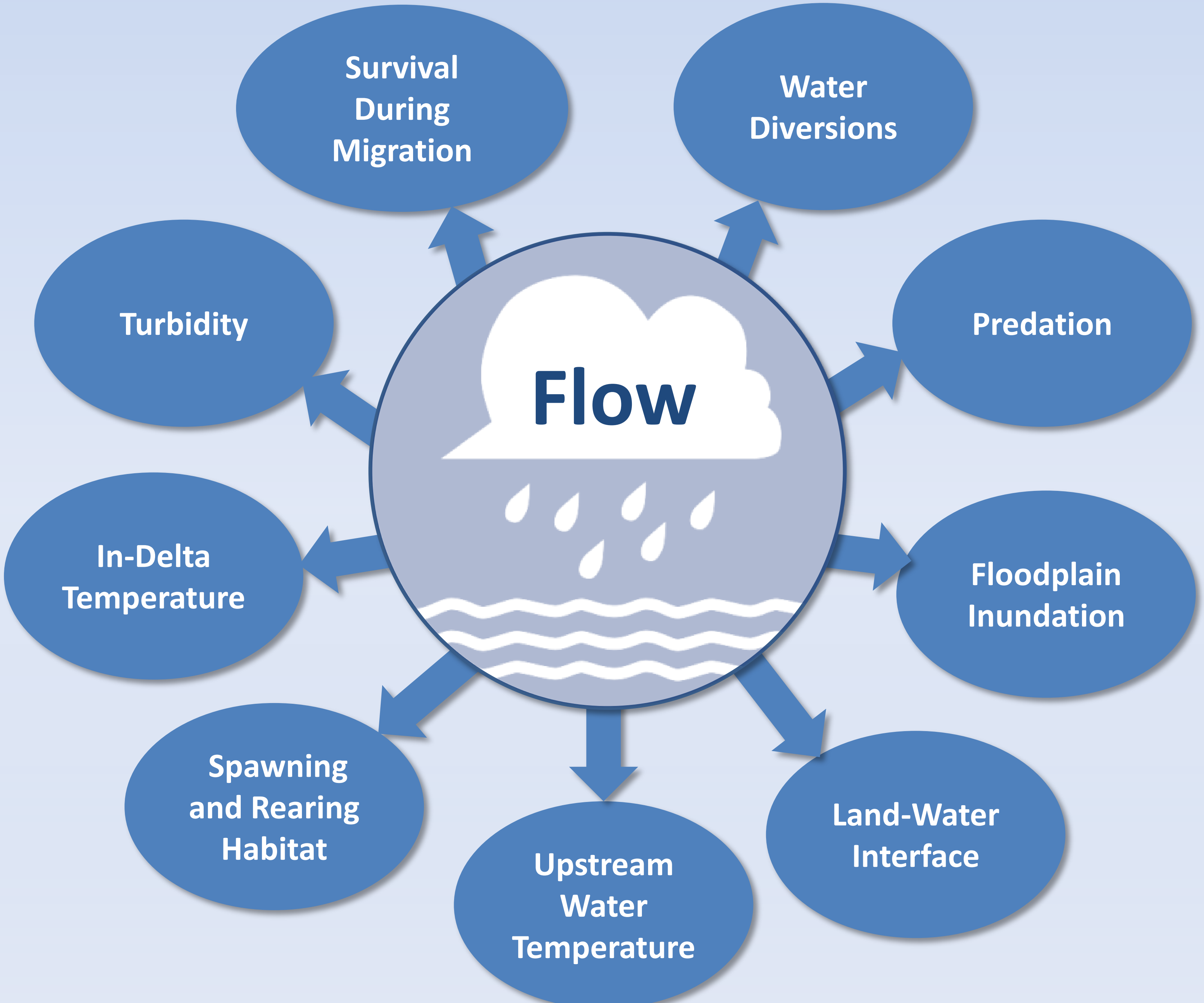
October 1-3, 2012

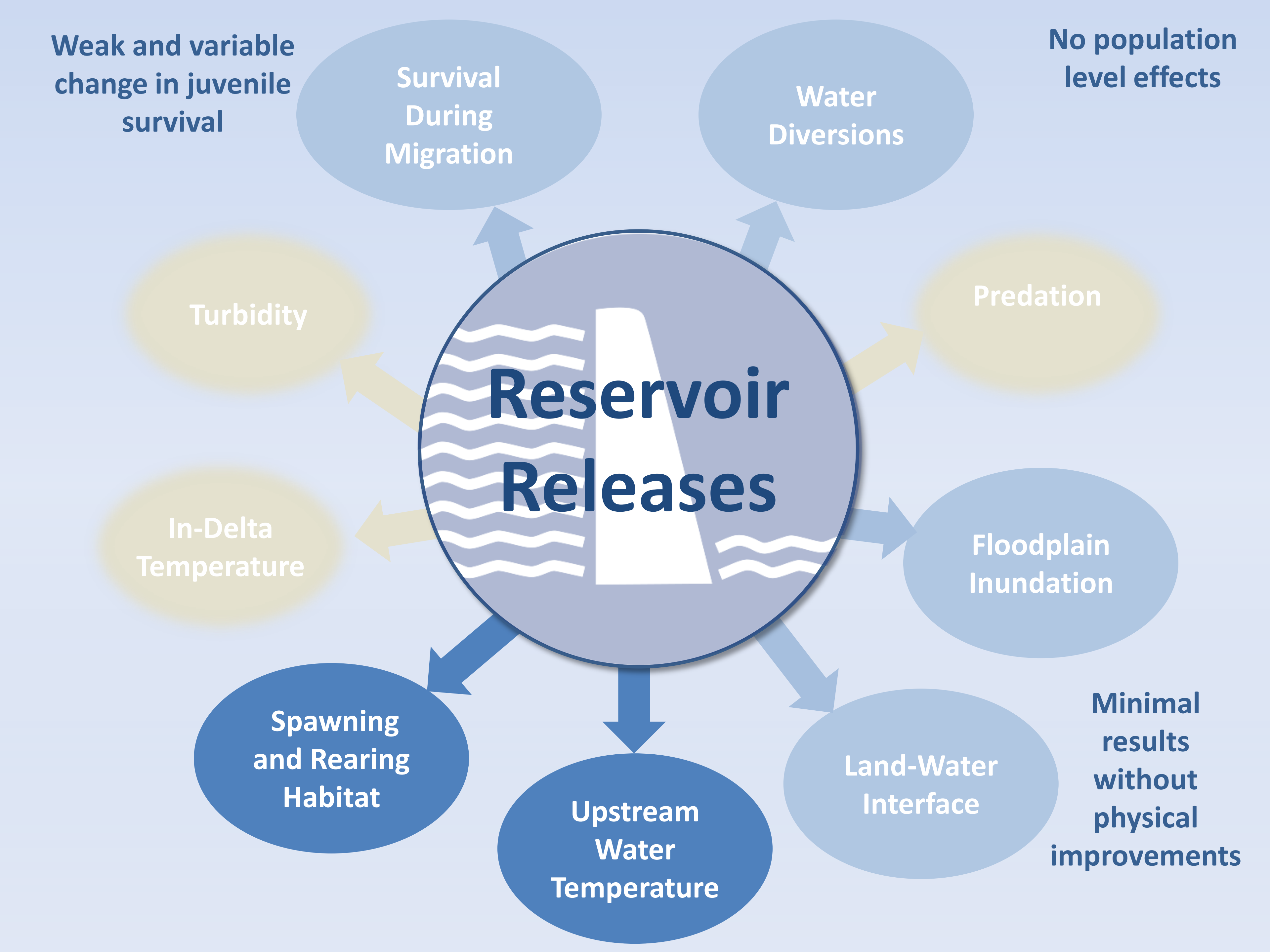
Objective: Provide a scientific basis for identifying potential recommendations based on opportunities and constraints of alternative management strategies.

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

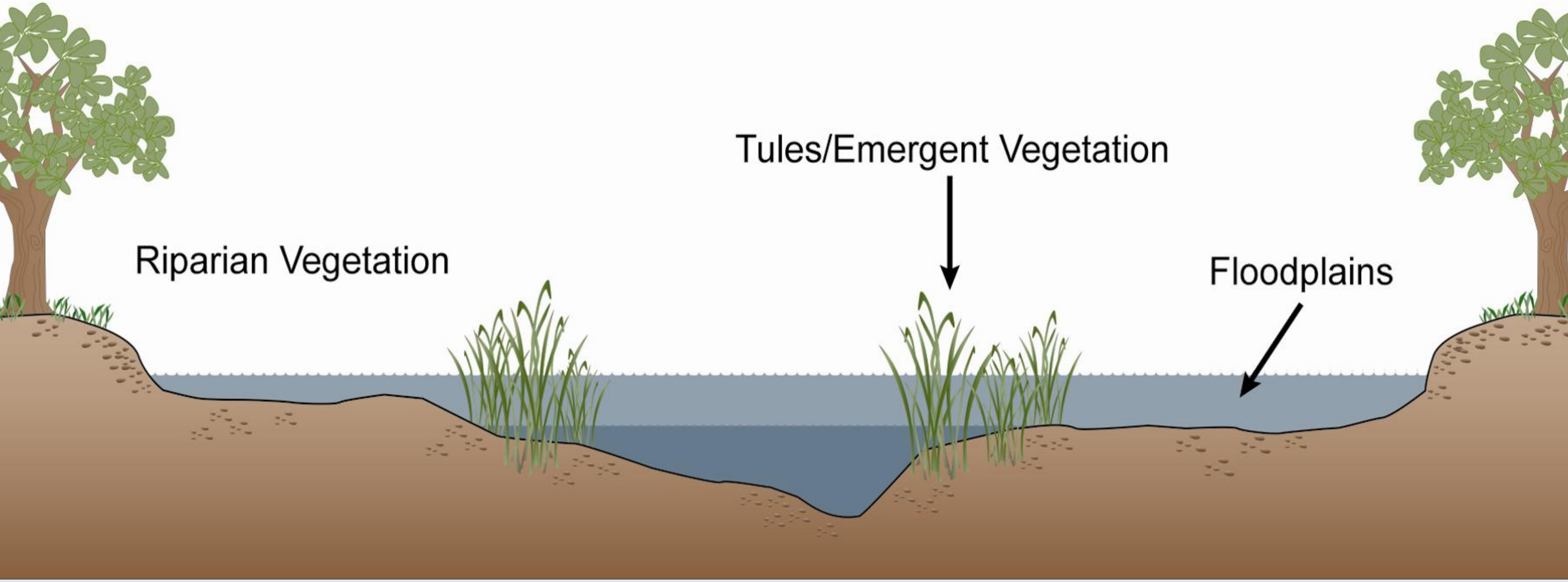
Presentation Organization

- Flow Functions and Reservoir Releases
- Stressors
- River Flow and Survival
- River Flow and Juvenile Migration Rates
- Water Temperature Management
- Effect of Exports on Survival
- Tidal Hydrodynamics and Flow
- Ocean Conditions
- Lifecycle Models
- Summary


Survival During Migration
Water Diversions
Turbidity
Predation
Flow
In-Delta Temperature
Floodplain Inundation
Spawning and Rearing Habitat
Upstream Water Temperature
Land-Water Interface

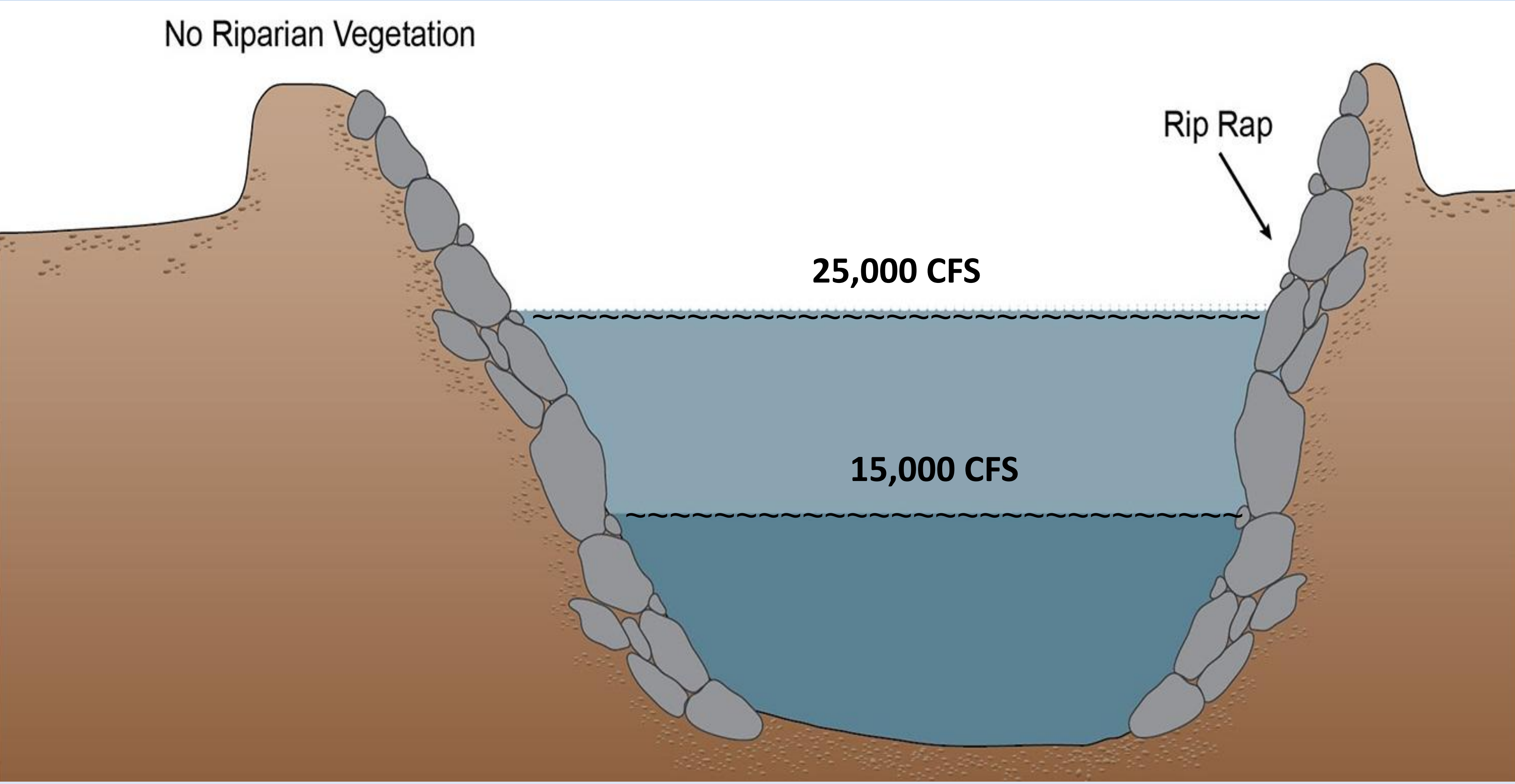

Weak and variable change in juvenile survival
Survival During Migration
Water Diversions
No population level effects
Turbidity
Predation
Reservoir Releases
In-Delta Temperature
Floodplain Inundation
Spawning and Rearing Habitat
Upstream Water Temperature
Land-Water Interface
Minimal results without physical improvements

Changes in habitat can be a function of changes in river flow



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

Flow functions are diminished in altered channel

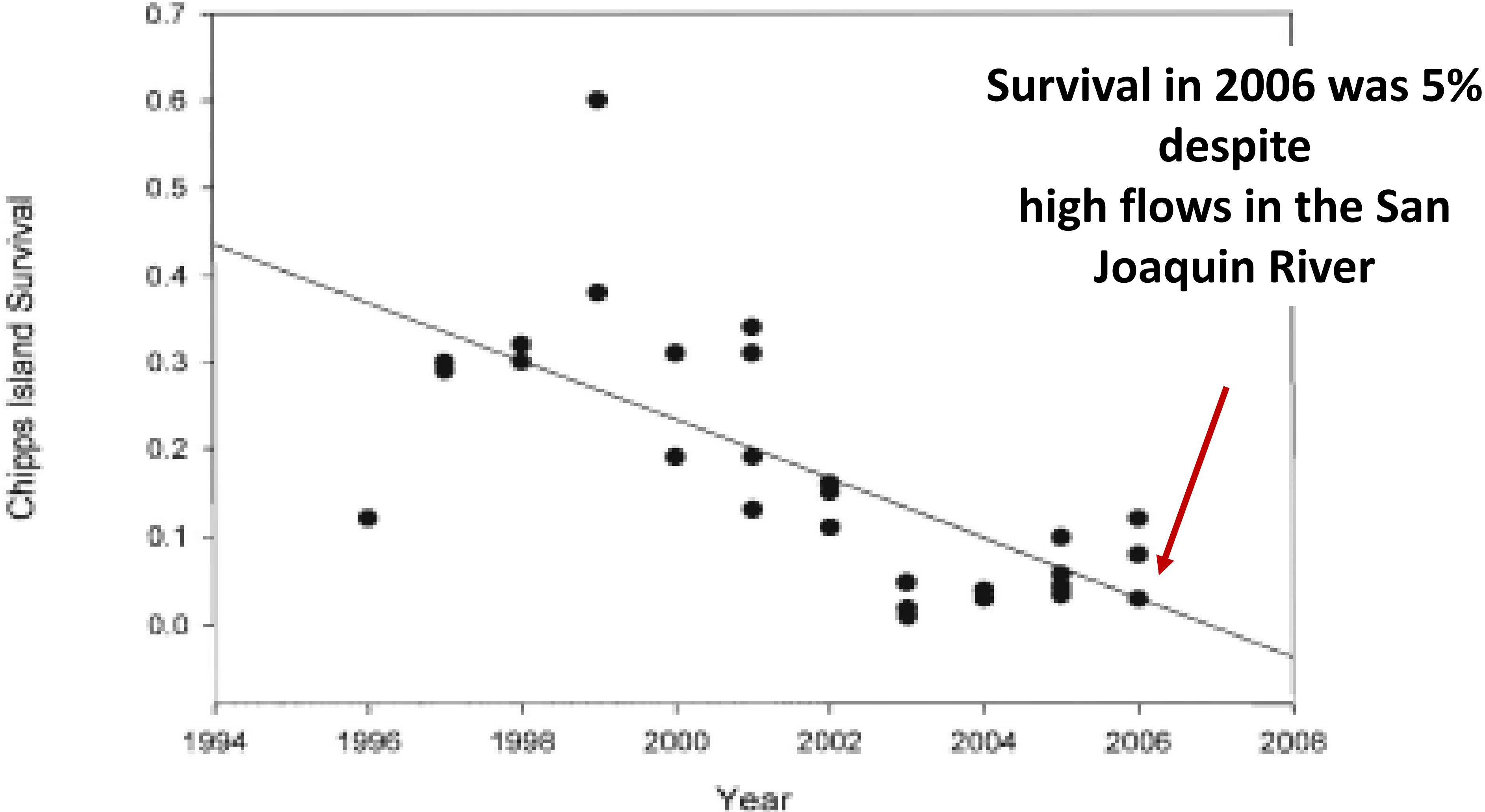


Cross-section through a channelized reach of the Sacramento River showing change in habitat as a function of changes in river flow.

Multiple interacting variables affect salmonid populations

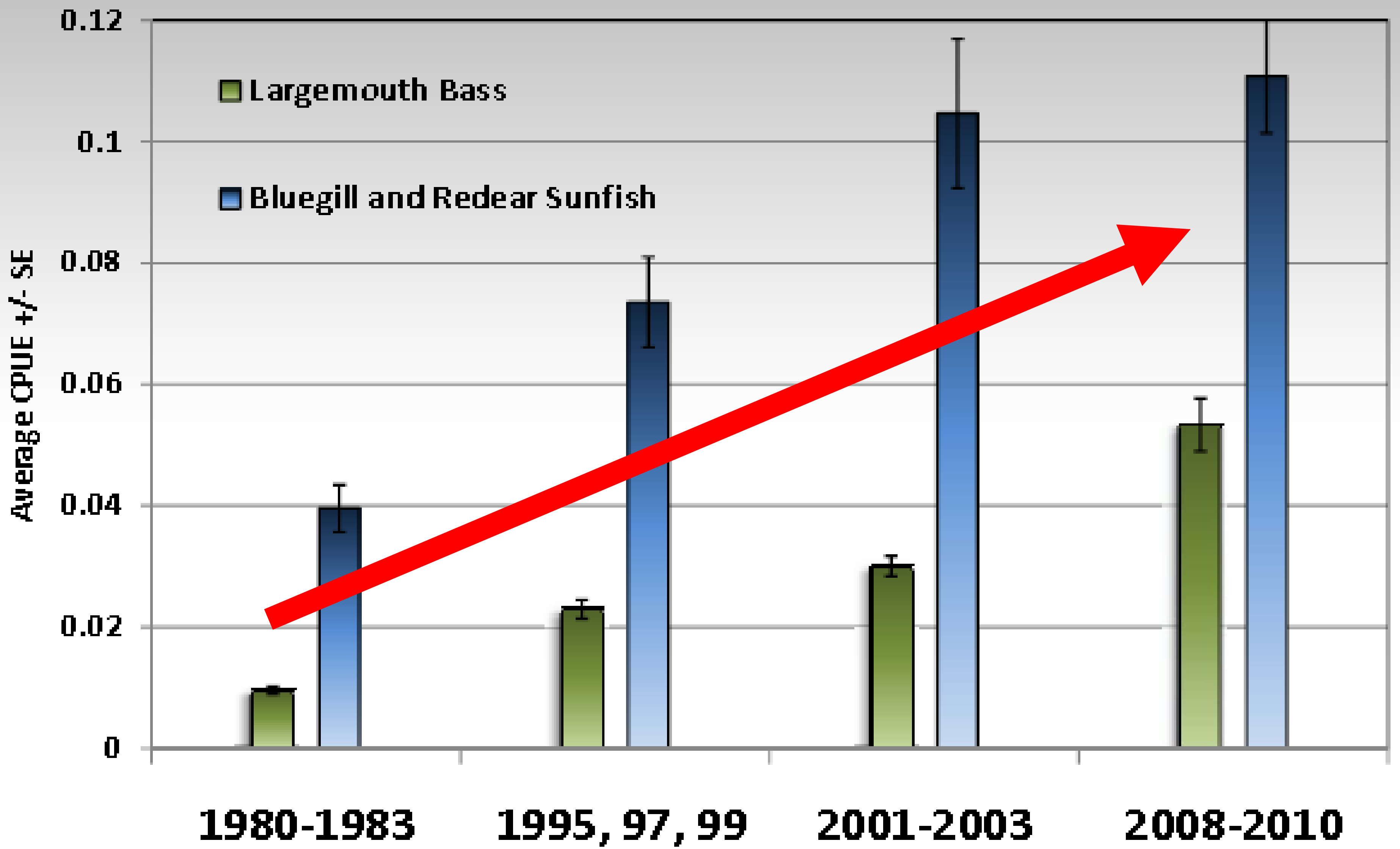
- Predation
- Water temperature
- Quality of spawning and rearing habitat
- Water diversions
- Channelization
- Reduced access to floodplains and wetlands
- Ocean rearing conditions
- Ocean harvest

Survival of juvenile San Joaquin River fall-run salmon has declined substantially in recent years



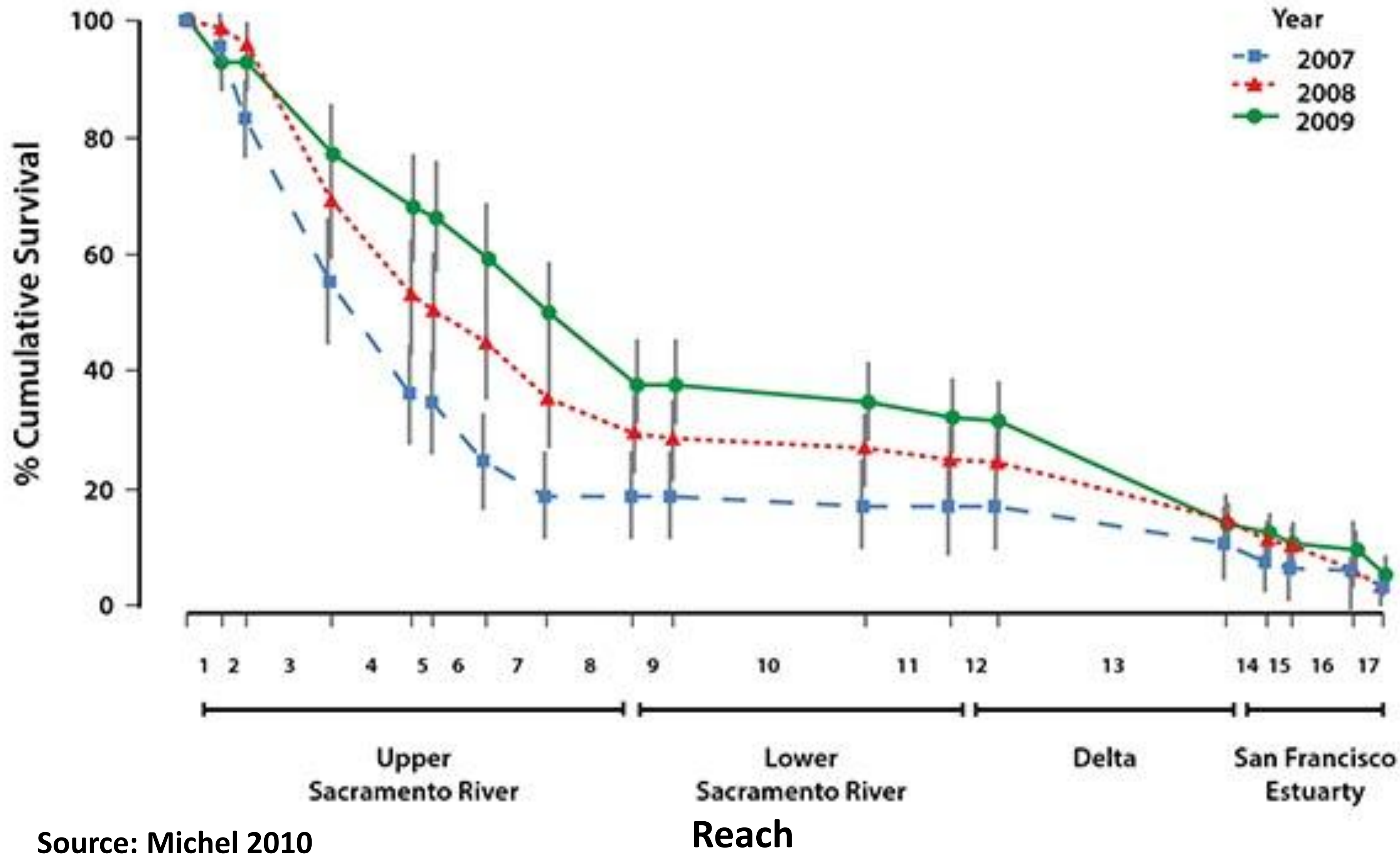
Data from VAMP studies: SJRGA 2006

Abundance of non-native predators has increased substantially in recent years in the Delta



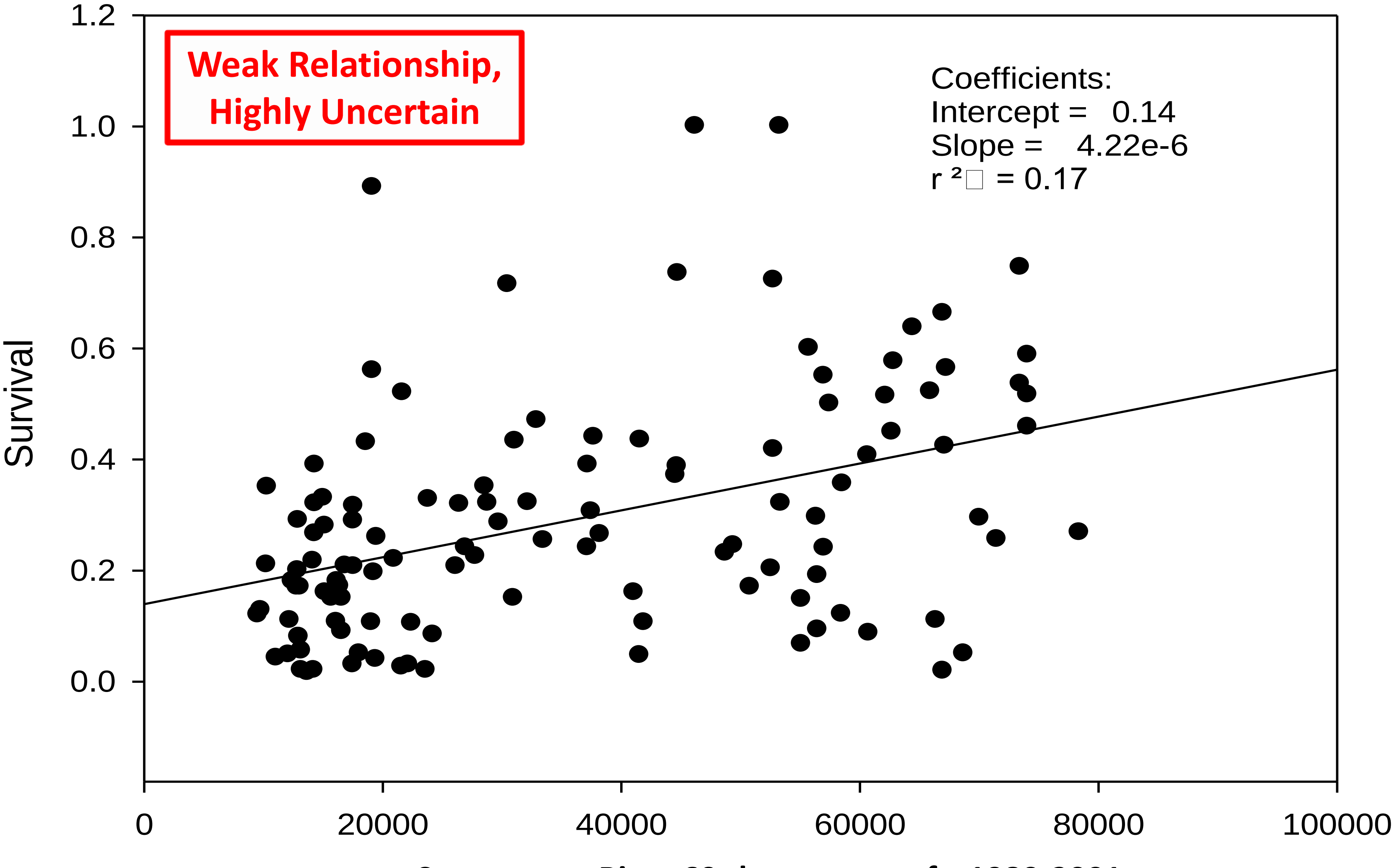
Source: Conrad et al. 2010a

Mortality rates of juvenile Chinook salmon are high

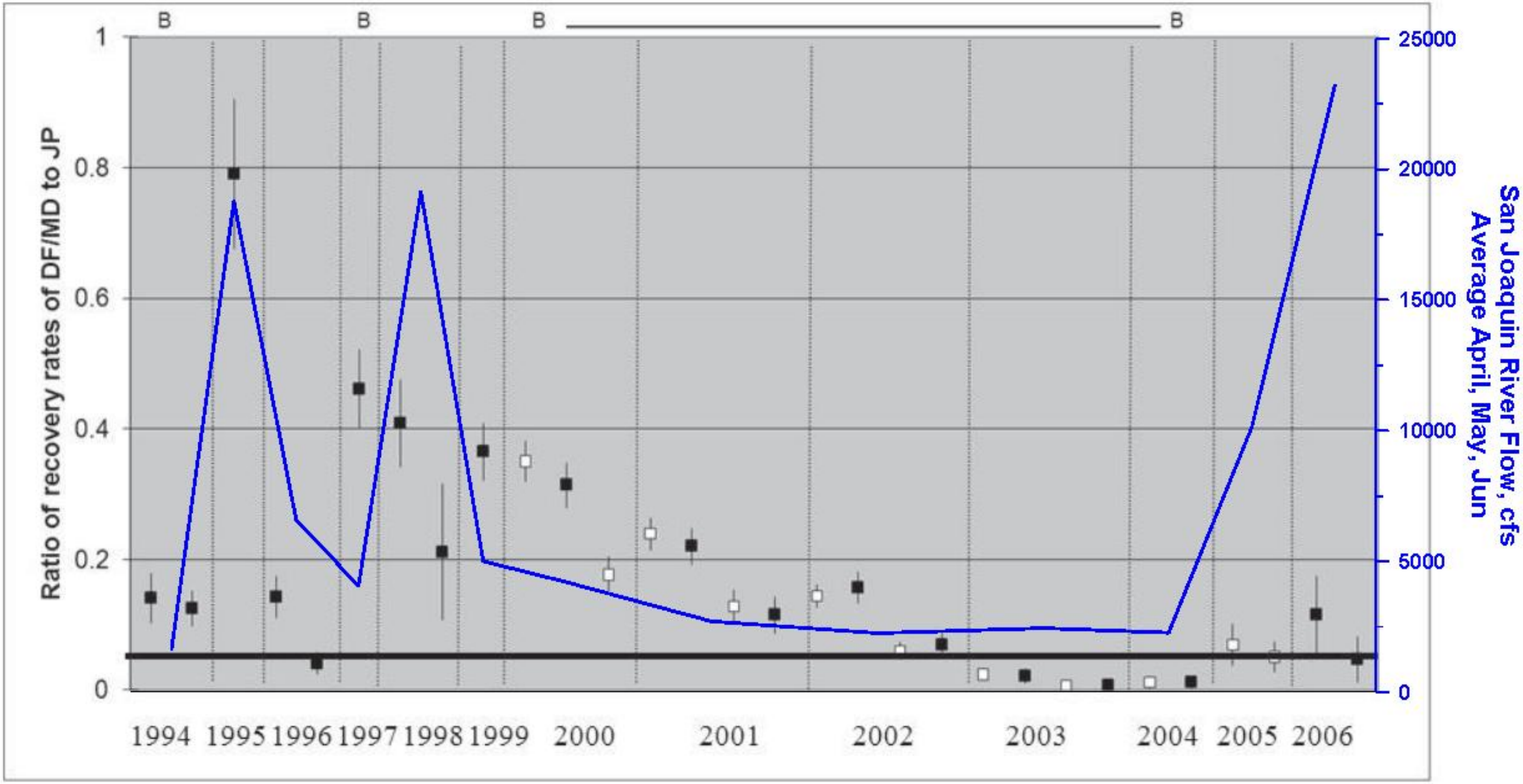


Source: Michel 2010

Juvenile salmon survival is weakly correlated with Sacramento River flow



Low survival in 2005 and 2006 in San Joaquin River was not related to flow



Estimates of smolt survival (+/- 2 Standard Errors) from Mossdale to Jersey Point during the VAMP between 1994 to 2006 using coded wire tagged fish. Years with the physical Head of Old River Barrier installed are denoted with B and are in 1994, 1997 and 2000-2004. The black line is the estimate of survival between Mossdale and Chipps Island in 2010 using acoustic tag technology and removing predator-type detections. (Brandes et al., 2008 and SJRG, 2011).

A poor relationship was observed between Sacramento River flow during juvenile migration in 2006 and 2009 and subsequent adult abundance

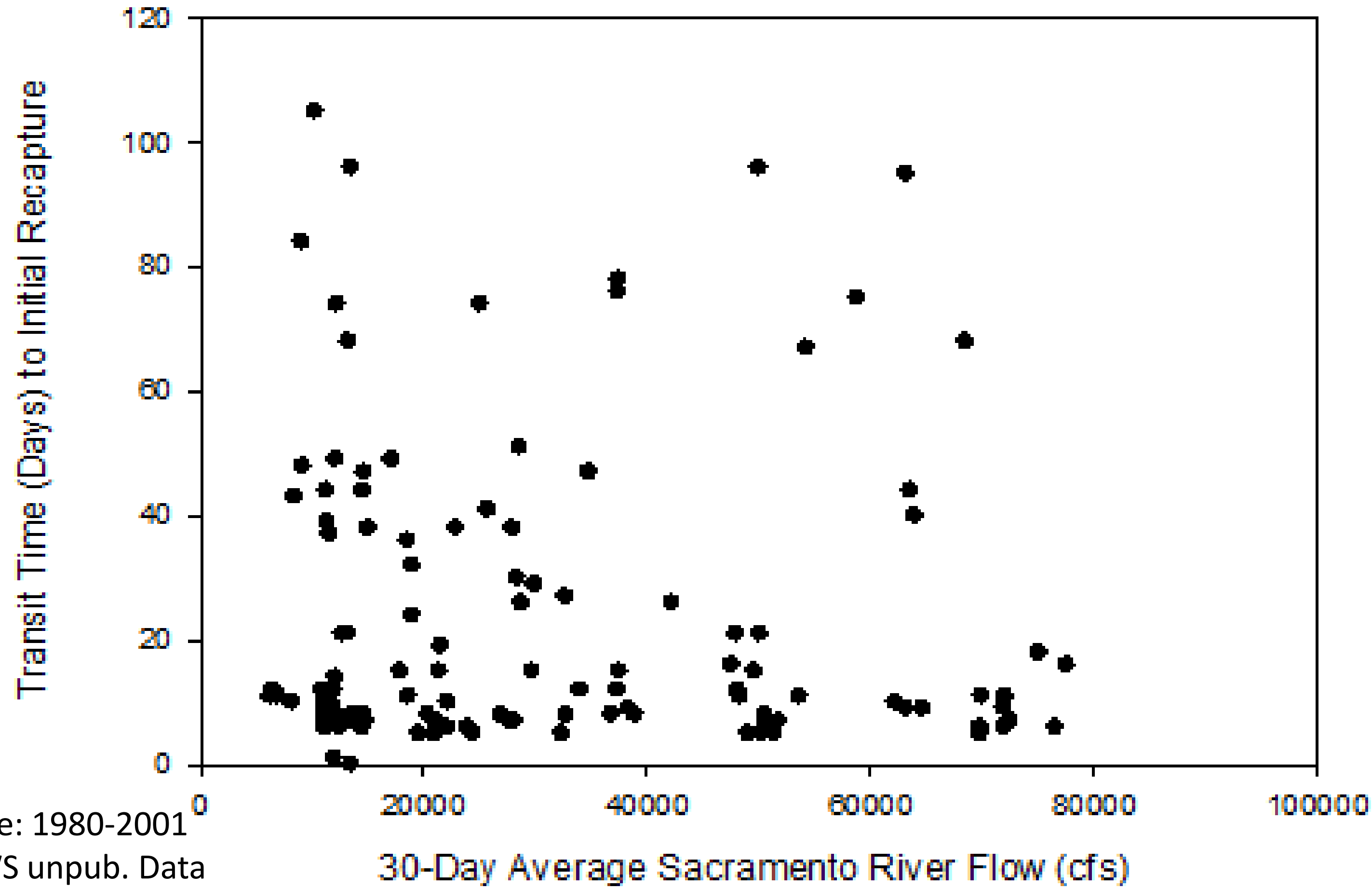
	2006	2009
Average January-May Sacramento River flow during juvenile migration	62,000 cfs	15,500 cfs
PFMC Estimated Adult Chinook salmon abundance 2.5 years later (assuming 3-year generation period)	53,000 adult salmon	819,000 adult salmon

Size and migration route effect juvenile salmon survival

- Fish size has significant effect on juvenile salmon survival
- Survival rates are higher for Sacramento River and lower for migration via interior Delta
- Non-physical barriers appear to reduce juvenile salmonid migration into interior Delta


Significant salmonid research is underway
Ongoing research will:
- Improve understanding of juvenile reach-specific survival
- Improve understanding of effects of river flow and tides on migration route
- Reduce uncertainty from earlier studies

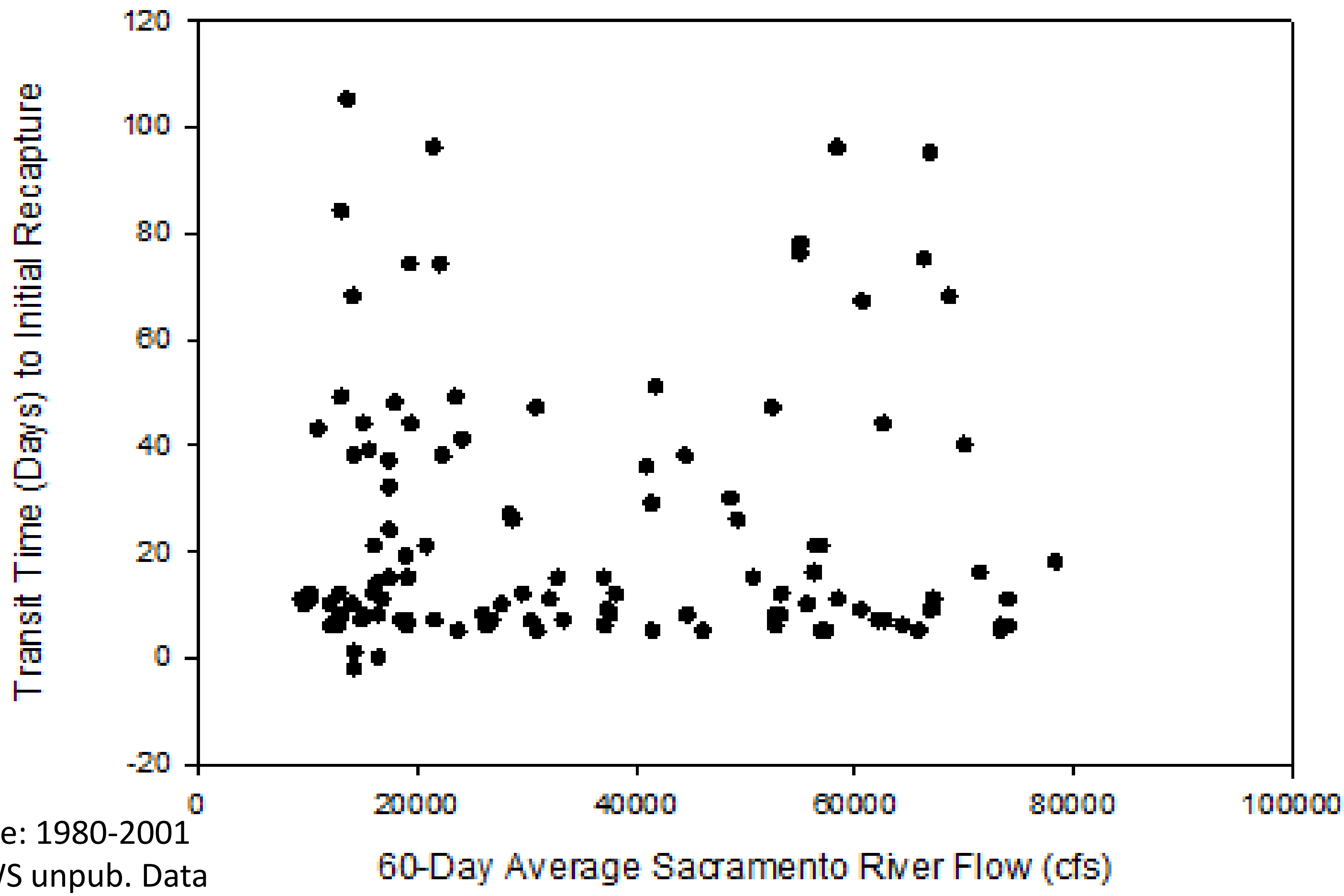
Juvenile salmon migration rate is independent of Sacramento river flow



Source: 1980-2001 USFWS unpub. Data

- ***Increased flow alone will not reduce duration of juvenile migration or vulnerability to predation***

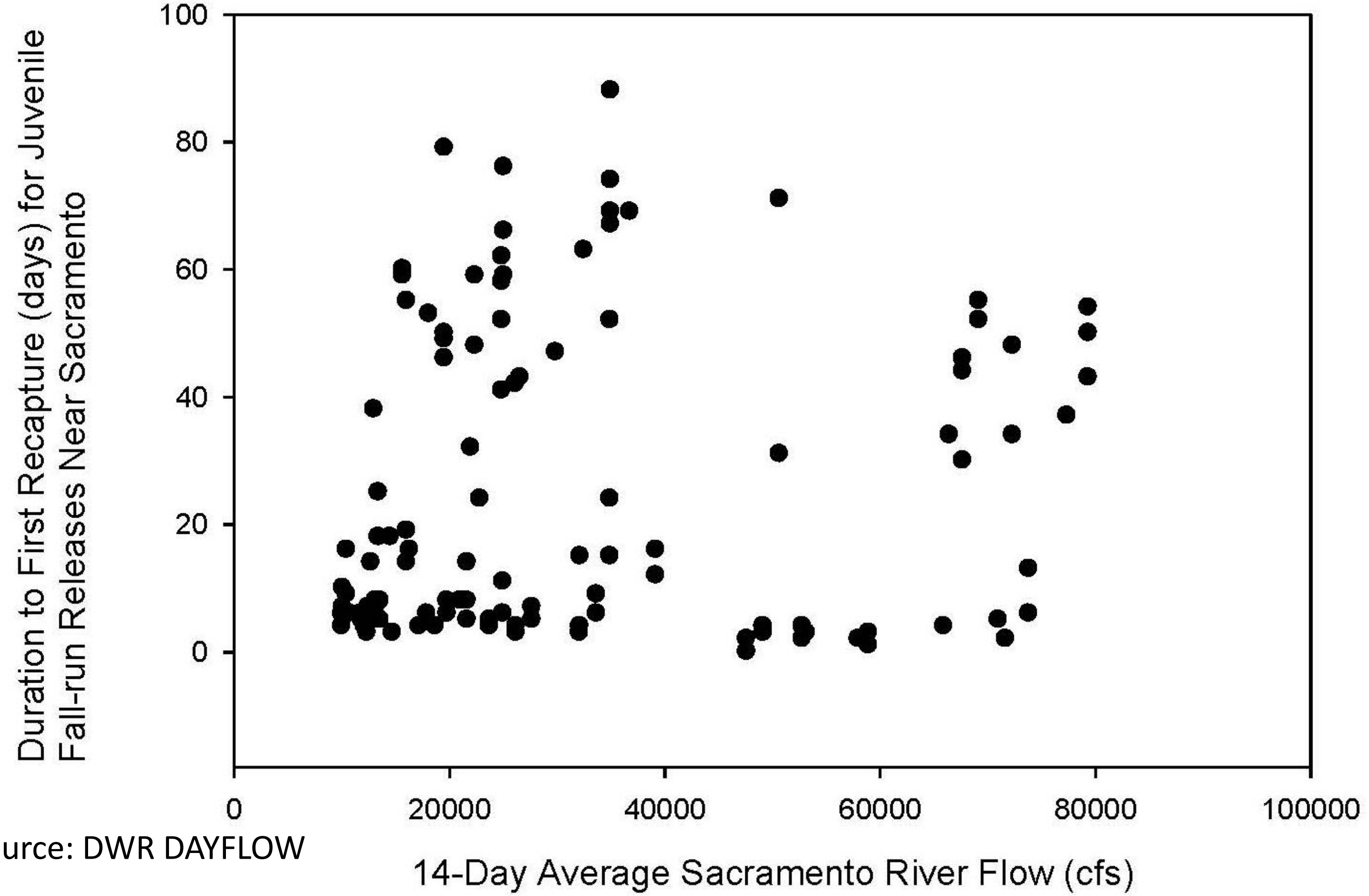
Juvenile salmon migration rate is independent of Sacramento River flow



Source: 1980-2001
USFWS unpub. Data

- ***Increased flow alone will not reduce duration of juvenile migration or vulnerability to predation***

Juvenile salmon migration rate is independent of Sacramento River flow



Source: DWR DAYFLOW

- ***Increased flow alone will not reduce duration of juvenile migration or vulnerability to predation***

Water temperature management within reservoirs is critical to maintaining suitable spawning and rearing habitat

- Release of cold water from reservoirs maintains cool temperatures immediately downstream
- Water temperature increases downstream-- eventually equilibrates with air temperature
- Reservoir releases have no effect on instream water temperatures for most of the lower reaches of the Sacramento and San Joaquin Rivers and the Delta.

Juvenile salmon survival through the Delta is independent of SWP/CVP export rate

- Survival largely independent of export:inflow ratio and OMR reverse flows.
- Salmon survival during Delta migration is not significantly related to SWP and CVP export rate.

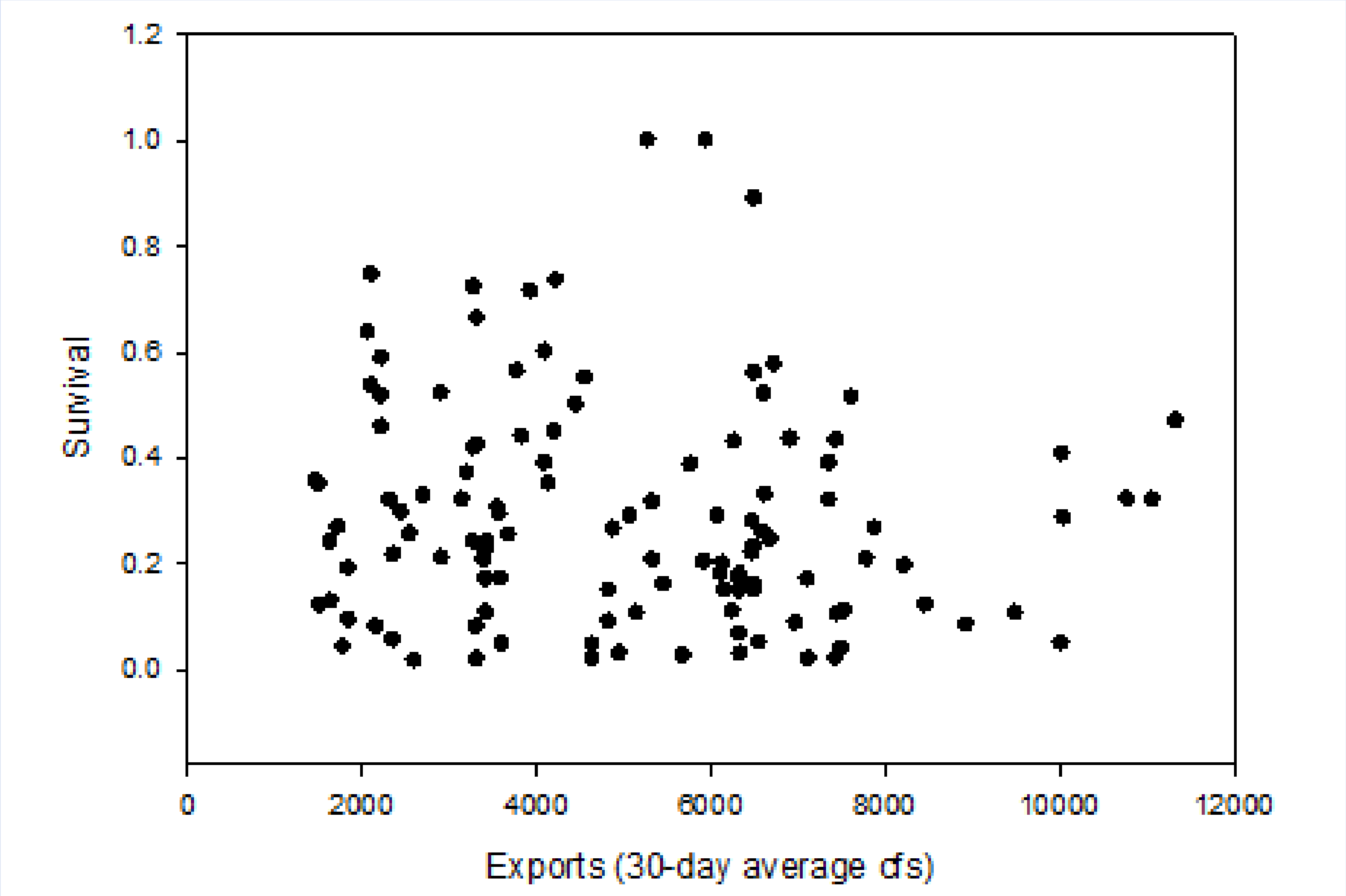
Salmon salvage at SWP-CVP facilities is extremely small percentage of juvenile outmigrants

1994-2007: 3.6 million tagged smolts

- Released in Battle Creek and Sacramento River upstream of the RBDD
- Juvenile Chinook salmon were marked with an adipose fin clip and coded wire tag
- Releases included fall-run, winter-run, spring-run, and late fall-run juvenile salmon

0.1% (0.0% to 0.5%) salvaged at SWP-CVP pumping plants

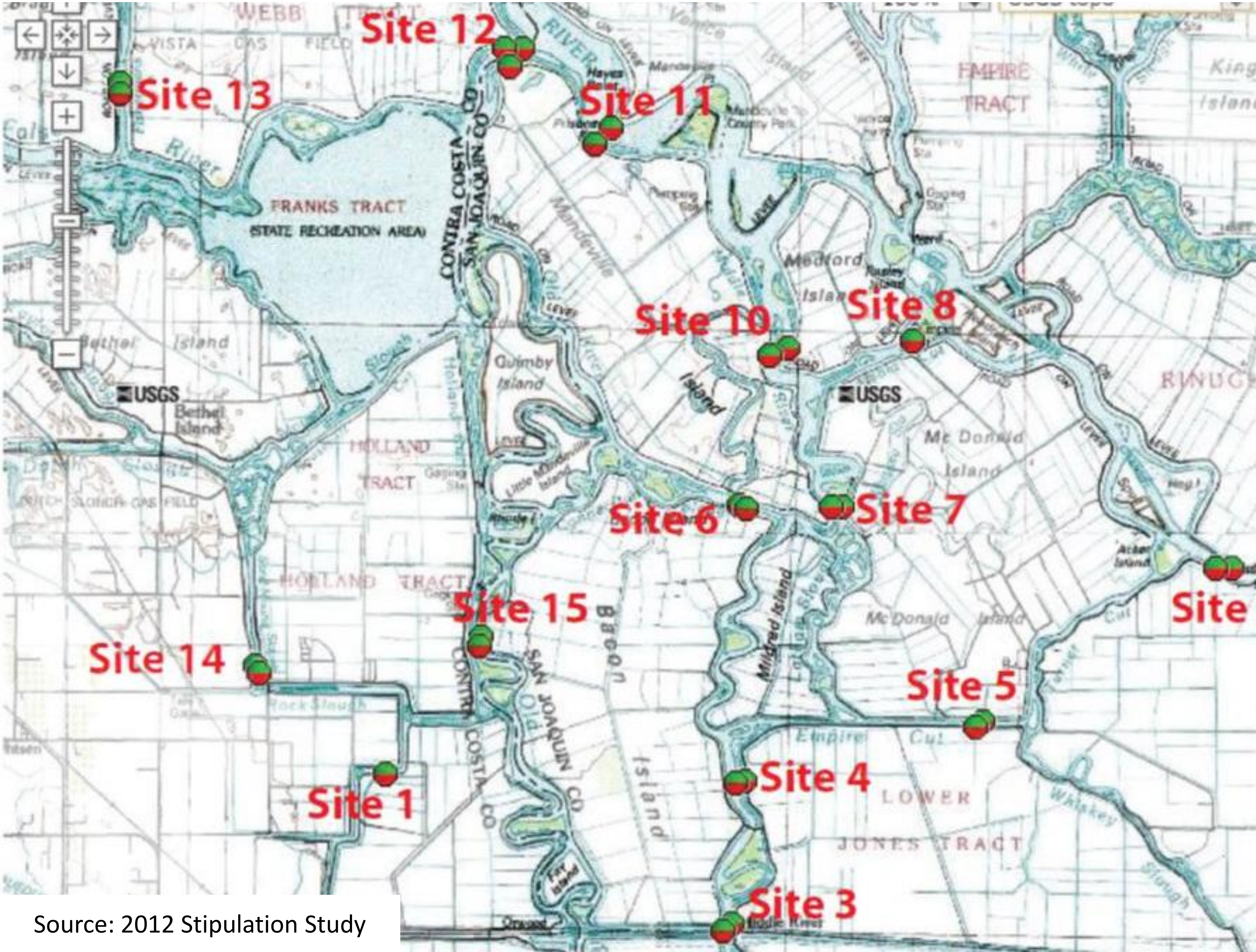
There is no relationship between smolt survival and SWP-CVP export rate



Tides dominate hydrodynamics in the Delta

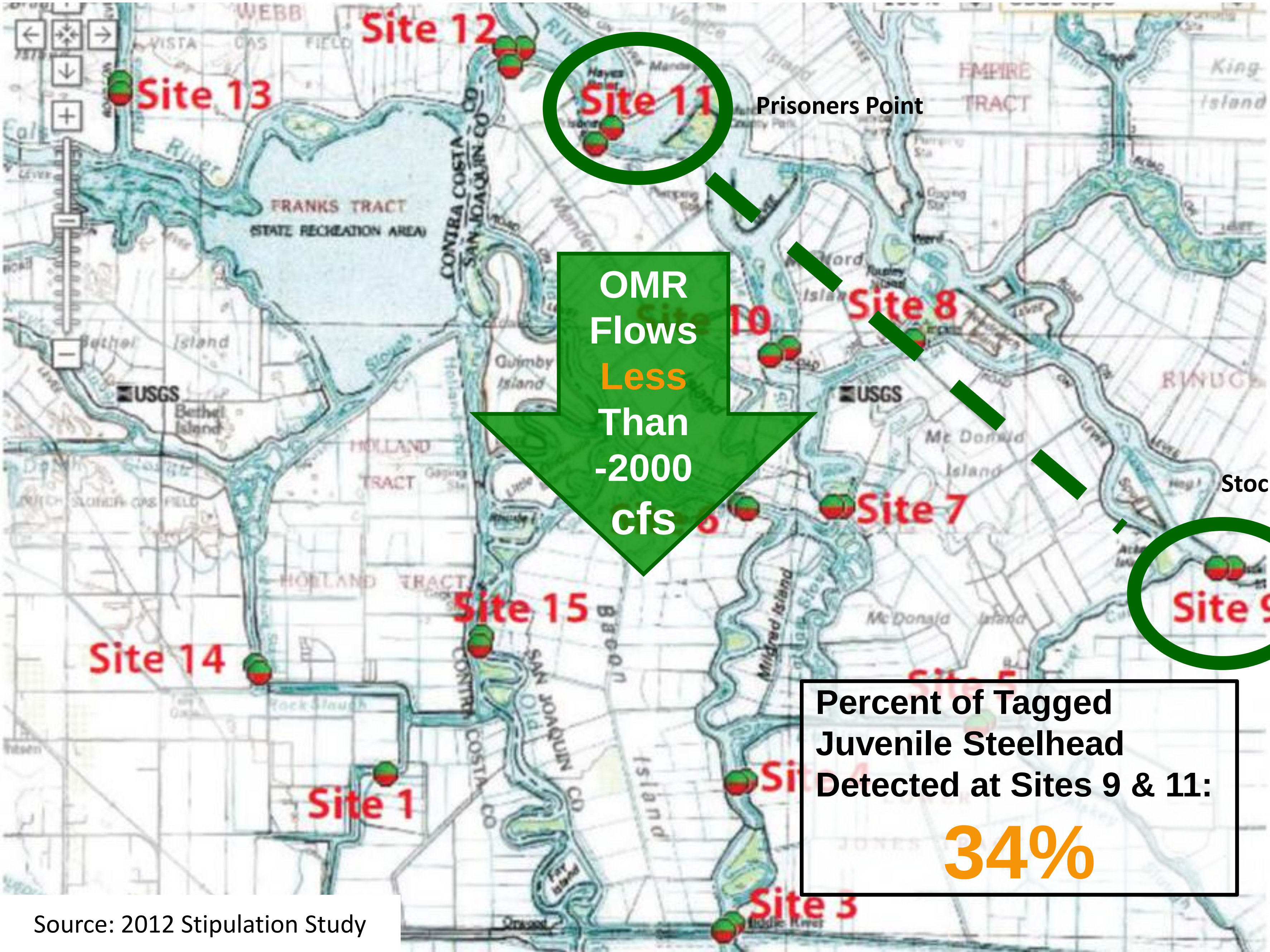
- Sub-daily tidal flows are a major factor affecting migration route selection
- Tidal flows overwhelm inflows in the western Delta (tidal flow frequently is approximately 10 times greater that Delta inflow)
- Increasing Delta inflow or outflows would not significantly affect salmonid migration rates

2012 Acoustic Tag Monitoring



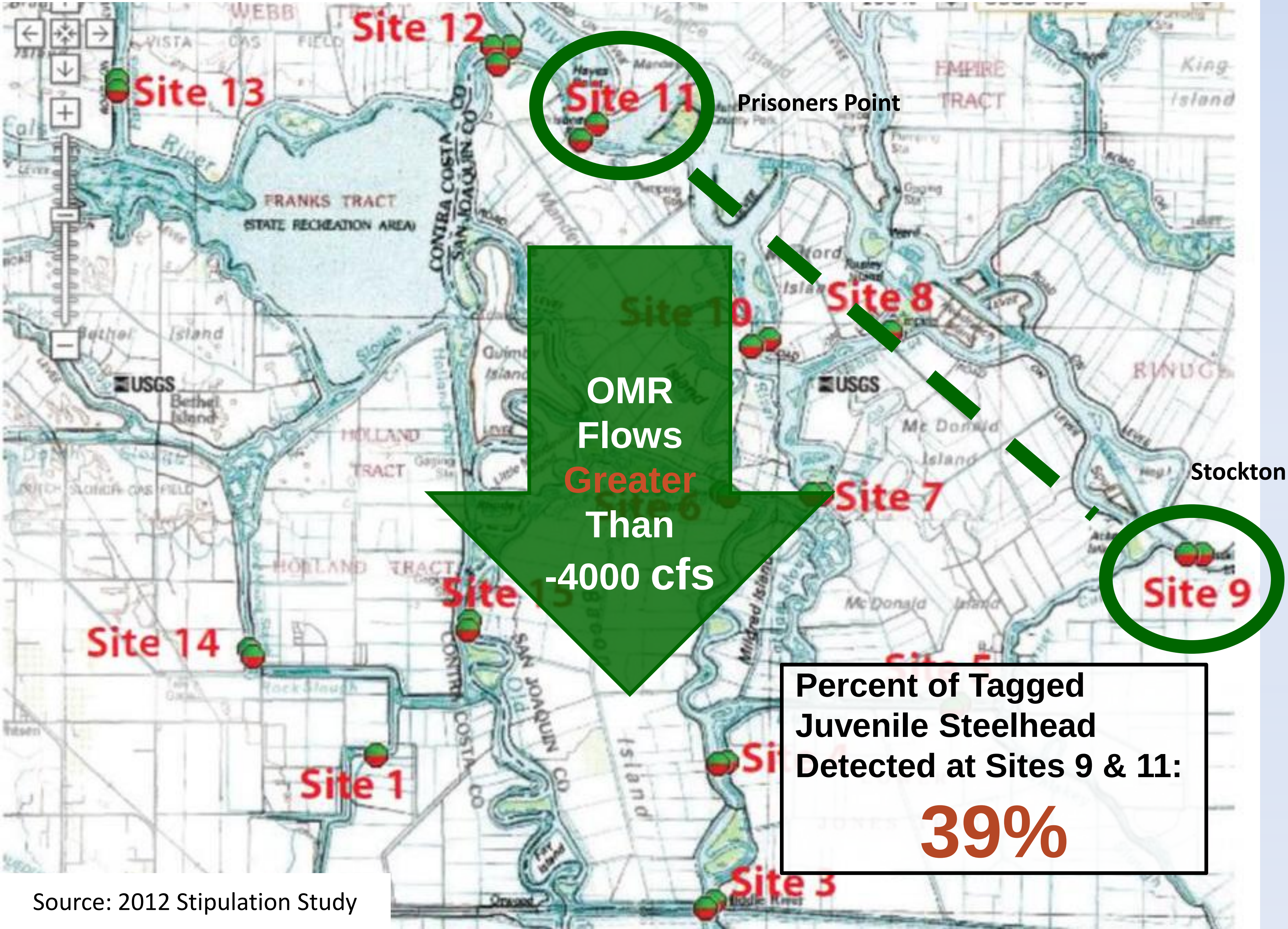
Source: 2012 Stipulation Study

2012 Acoustic Tag Monitoring



Source: 2012 Stipulation Study

2012 Acoustic Tag Monitoring

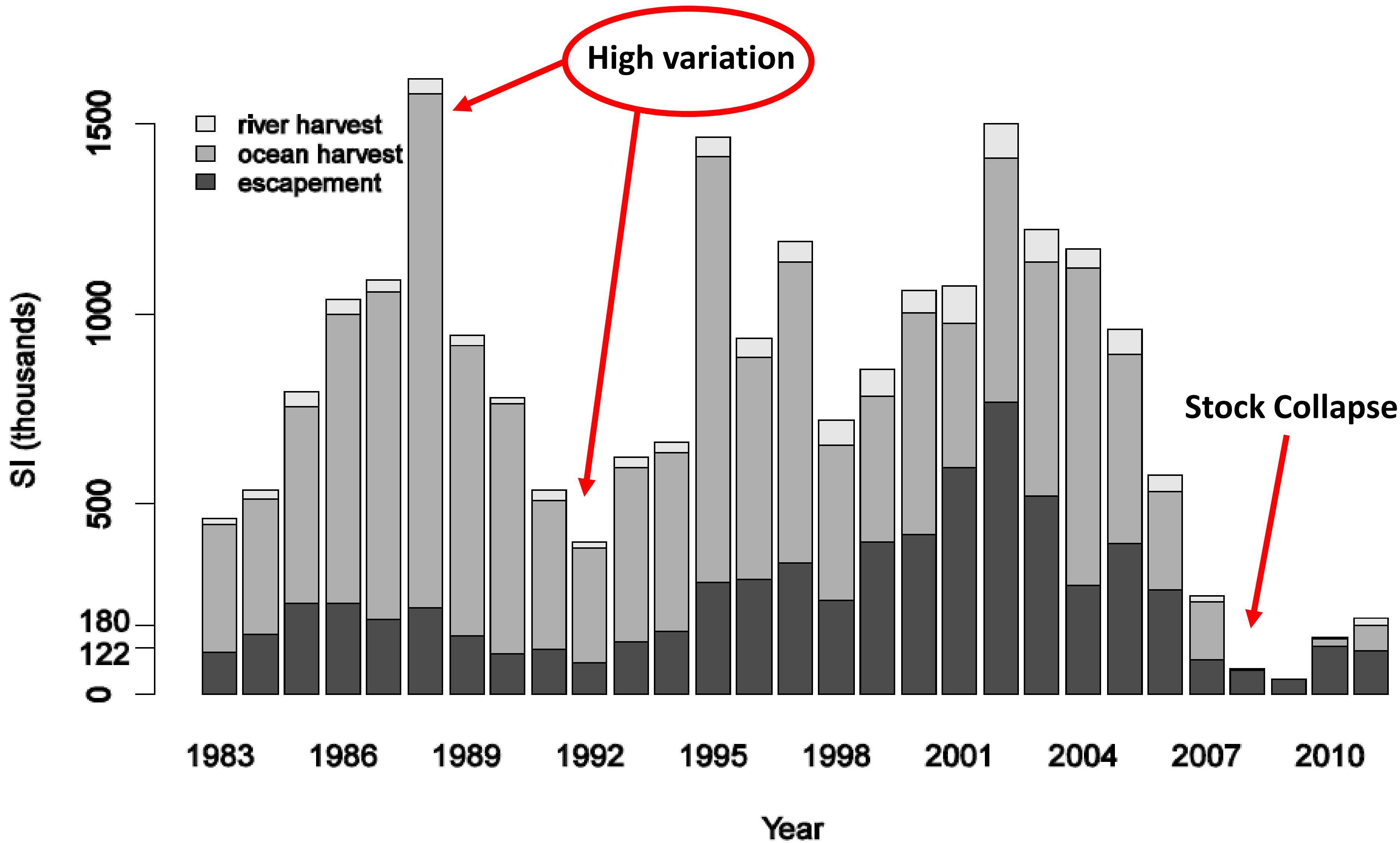


Source: 2012 Stipulation Study

Integrating best available science:

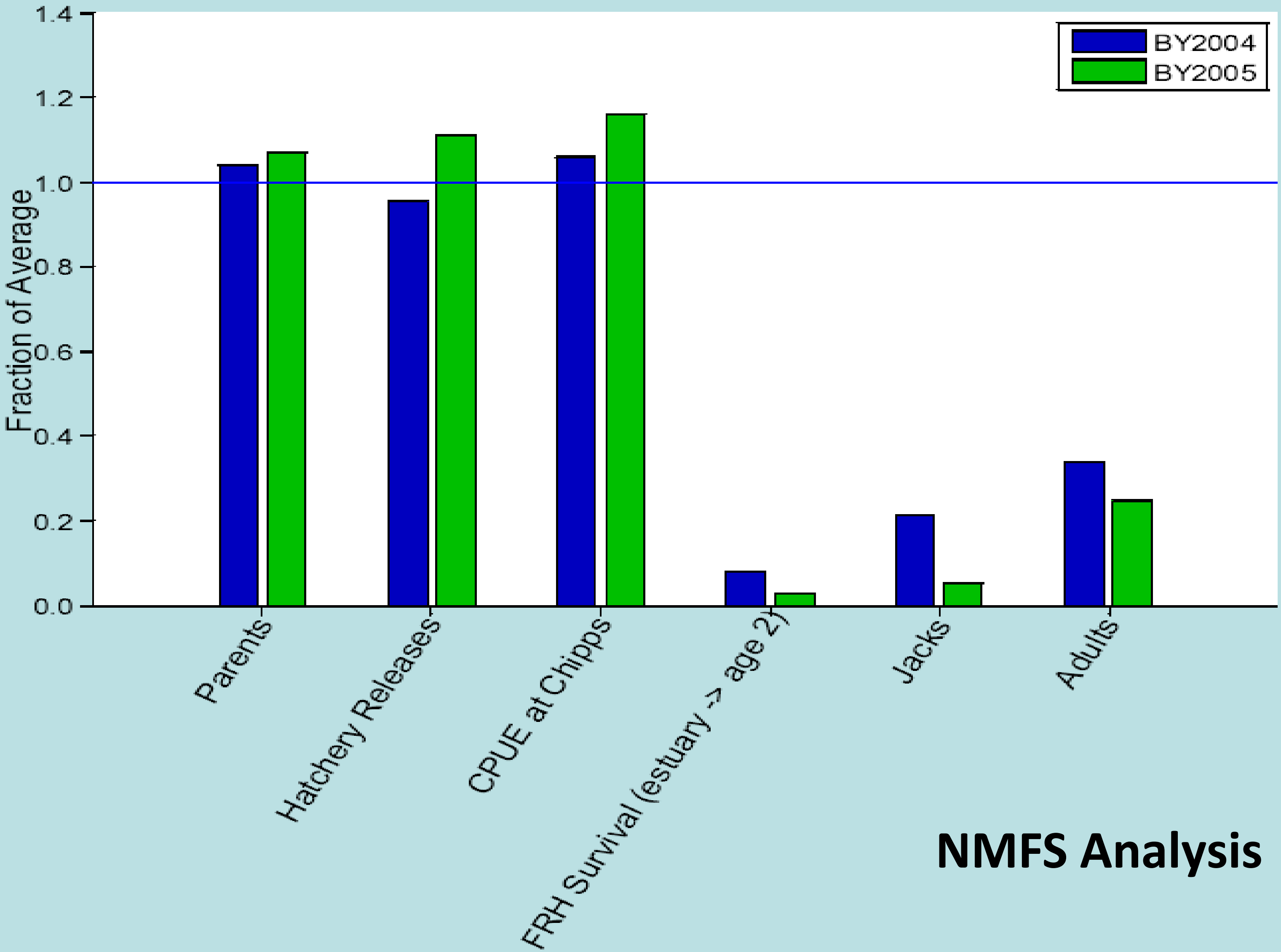
- Accounting for all the variables
- Discerning what matters most
- Discovering balanced solutions to competing needs

Sacramento Index (SI) of Fall Chinook Abundance



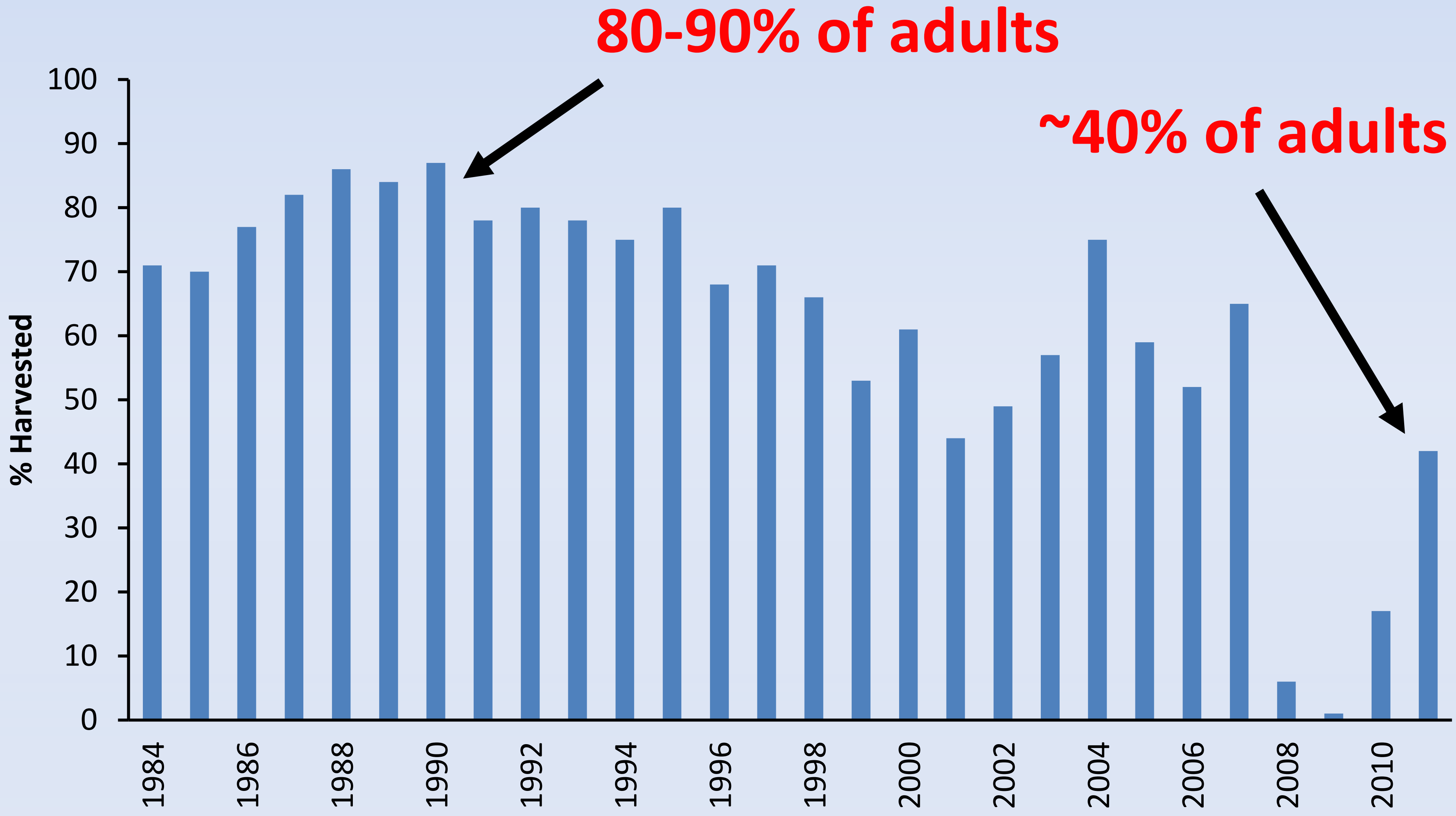
Source: Pacific Fisheries Management Council. 2012. Preseason report 1 for 2012 ocean salmon fishery regulations

Ocean factors caused collapse of Chinook runs in 2008-2009



NMFS Analysis

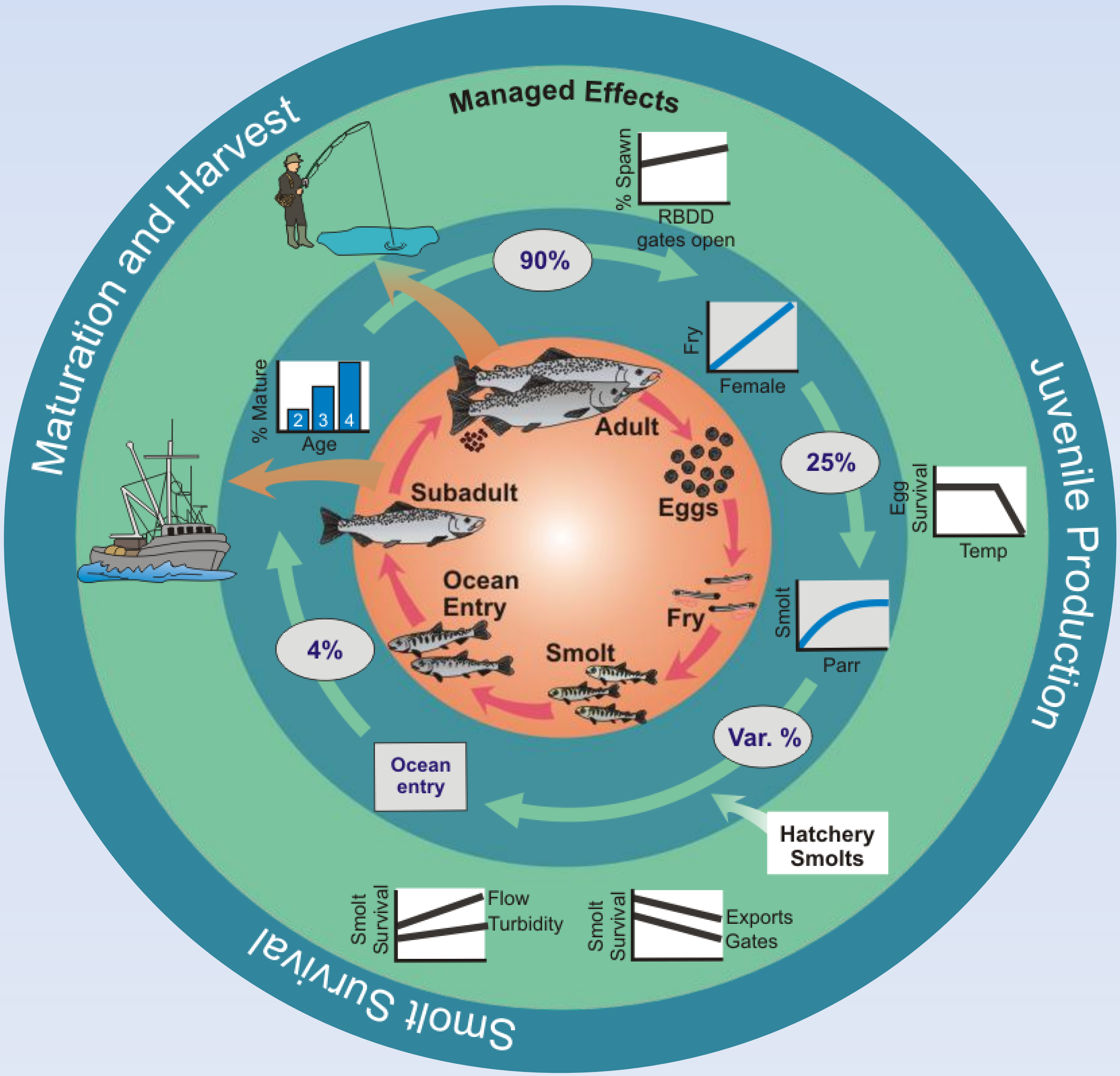
Ocean harvest has large impact

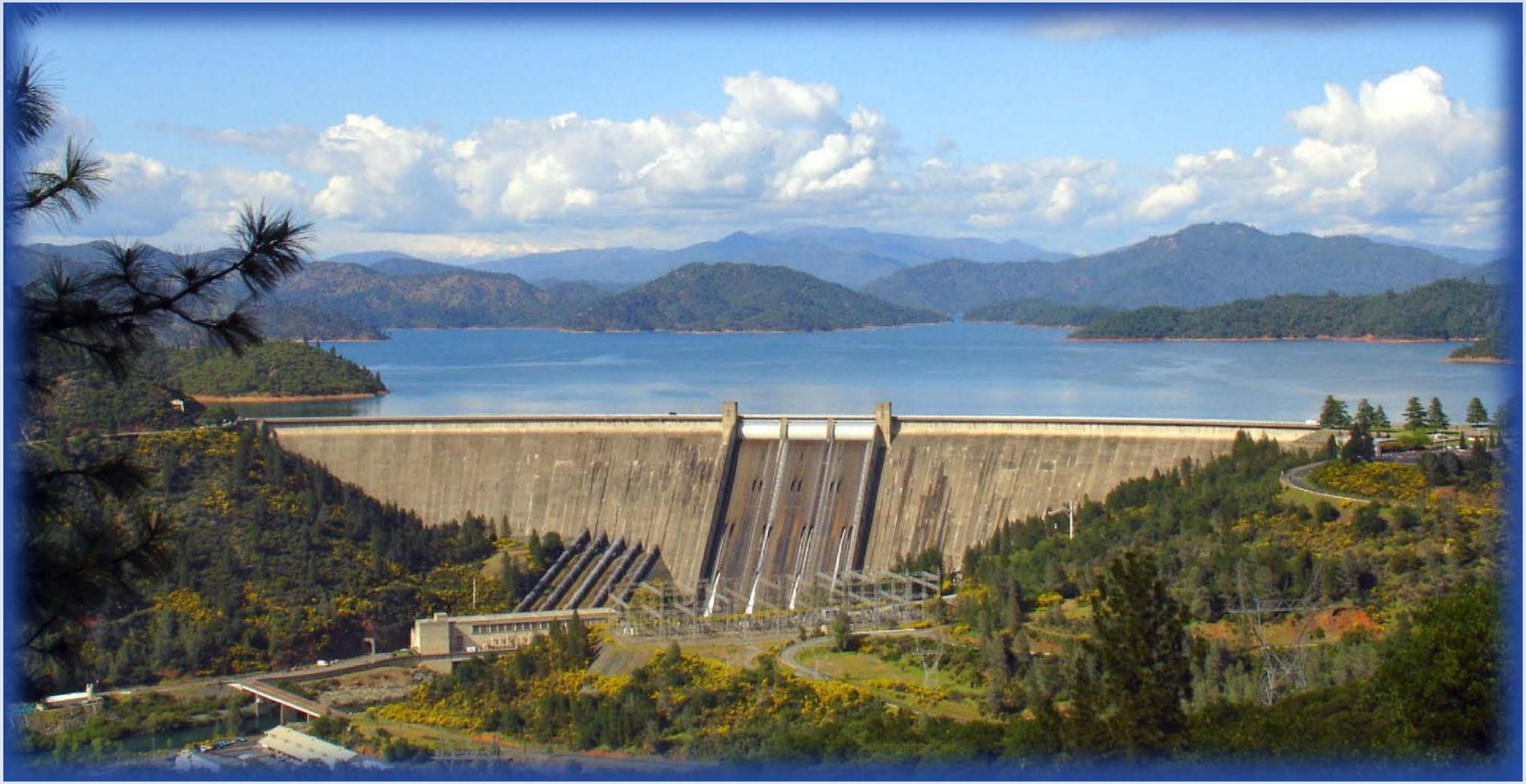


Source: PMFC 2012

CV Chinook Salmon

Application of lifecycle models





Finding science solutions:

- Rely on recent studies with best technologies
- Beware of correlated explanatory variables
- Accumulate factor effects across all life stages
- Express effects in adult equivalents
- Use temporally and spatially explicit life-cycle models to compare management scenarios

Summary:

SCIENTIFIC FINDINGS THAT SUPPORT RECOMMENDATIONS:

- Majority of natural flow functions cannot be replicated through reservoir releases
- Large changes in flow produce small, uncertain changes in juvenile survival
- Increases in flow may adversely impact reservoir cold water reserves and carryover storage
- Salmon survival largely independent of pumping rates at CVP/SWP Delta Facilities
- Ocean conditions, ocean harvest, and predation have large influences on survival and abundance of salmonids
- Juvenile salmon mortality of 75% or more upstream of the Delta is high compared to other large-river systems

RECOMMENDED FOCUS FOR STATE BOARD:

- Protect cold water pool to maintain suitable temperatures for spawning and rearing
- Support creation, restoration and conservation of floodplain and other habitats
- Support use of non-physical barriers and other mechanisms to decrease salmonid migration into the Interior Delta

Today's Science Presentation

- Salmon
- **Pelagic Fish**

Key Points for Delta smelt

- Life cycle modeling indicates that key drivers are food, temperature, and predation

- Nutrients are important drivers of food web productivity

- No statistical foundation supporting a relationship between X2 and Delta smelt abundance in any season

- Neither low salinity zone nor X2 define habitat

- Entrainment does not drive abundance. Operations sensitive to OMR and turbidity have successfully ended large entrainment events.

Key Points for Longfin Smelt

- There is no demonstrated mechanism to explain the longfin FMWT: X2 correlation.

- Even if outflow *per se* increased abundance, the increases would be very small.

- Many factors other than flows are correlated with longfin smelt abundance. The most plausible causal mechanism for longfin abundance is food supply and ultimately nutrient patterns.

- Different longfin surveys show different long-term abundance trajectories.

Pelagic Presentation Outline

- Lifecycle Modeling; Entrainment
  - Dr. Richard Deriso
- Fall X2 and Delta smelt abundance
  - Dr. Noble Hendrix
- Outflow and Longfin smelt abundance
  - David Fullerton
- Ammonium inhibition and the foodweb
  - Dr. Richard Dugdale

Next up: Dr. Richard Deriso, IATTC

Life cycle model and delta smelt entrainment

Life Cycle Modeling

- A life cycle model is a common tool used to analyze species population decline

- Life cycle model results may provide essential information to future species management actions

A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt (*Hyposmesus transpacificus*)

Mark N. Maunder and Richard B. Deriso

Abstract: Multiple factors acting on different life stages influence population dynamics and complicate the assessment and management of populations. To provide appropriate management advice, the data should be used to determine which factors are important and what life stages they impact. It is also important to consider density dependence because it can modify the impact of some factors. We develop a state–space multistage life cycle model that allows for density dependence and environmental factors to impact different life stages. Models are ranked using a two-covariates-at-a-time stepwise procedure based on AIC_c model averaging to reduce the possibility of excluding factors that are detectable in combination, but not alone. Impact analysis is used to evaluate the impact of factors on the population. The framework is illustrated by application to delta smelt (*Hyposmesus transpacificus*), a threatened species that is potentially impacted by multiple anthropogenic factors. Our results indicate that density dependence and a few key factors impact the delta smelt population. Temperature, prey, and predators dominated the factors supported by the data and operated on different life stages. The included factors explain the recent declines in delta smelt abundance and may provide insight into the cause of the pelagic species decline in the San Francisco Estuary.

Résumé : Les multiples facteurs qui agissent sur les différents stades du cycle biologique influencent la dynamique des populations et compliquent l'évaluation et la gestion des populations. Afin de fournir des avis de gestion appropriés, il faut utiliser les données pour déterminer quels facteurs sont importants et quels stades du cycle ils affectent. Il est aussi important de considérer la densité dépendance, car elle peut modifier l'impact de certains facteurs. Nous mettons au point un type de modèle état–espace à stades de vie multiples qui tient compte de l'impact de la densité dépendance et des facteurs du milieu sur les différents stades de vie. Les modèles sont placés par ordre à l'aide d'une procédure pas-à-pas de deux covariables à la fois basée sur l'établissement de la moyenne des modèles de type AIC_c afin de réduire la possibilité d'exclure des facteurs décelables en combinaison, mais non isolément. Une analyse d'impacts sert à évaluer les effets des facteurs sur la population. Nous illustrons ce cadre d'analyse en l'appliquant à l'éperlan du delta (*Hyposmesus transpacificus*), une espèce menacée qui est potentiellement affectée par de multiples facteurs anthropiques. Nos résultats montrent que la densité dépendance et quelques facteurs clés affectent la population d'éperlans du delta. La température, les proies et les prédateurs dominent parmi les facteurs révélés par les données et ils agissent sur différents stades de vie. Les facteurs retenus expliquent les déclins récents de l'abondance de l'éperlan du delta et peuvent fournir une perspective sur la cause de la diminution des espèces pélagiques dans l'estuaire de San Francisco.

[Traduit par la Rédaction]

Introduction

Multiple factors acting on different life stages influence population dynamics and complicate the assessment and management of natural populations. To provide appropriate management advice, the available data should be used to determine which factors are important and what life stages they impact. It is also important to consider density-dependent processes because they can modify the impact of some factors, and the strength of density dependence can vary among life stages (Rose et al. 2001). Management can then better target limited resources to actions that are most effective. Unfortunately, the relationships among potential factors, the life stages that they influence, and density dependence are often difficult to piece together through standard correlation or linear regression analyses.

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Corresponding author: Mark N. Maunder (e-mail: mmaunder@iattc.org).

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Maunder & Deriso
Life Cycle Model Specifics

- Represents all life cycle stages of smelt (larval, juvenile, adult) and how population abundance changes between stages

- Allows multiple factors or covariates to influence survival and stock-recruit relationships

- Data spans 1972-2010

Model Conclusions

- Food abundance, temperature, predator abundance, and density dependence are the most critical factors impacting the Delta smelt population
- Entrainment from water export operations is <u>NOT</u> an important factor impacting smelt population growth rate
- Fall X2 is <u>NOT</u> an important factor impacting smelt population growth rate
- Efforts should be focused on addressing environmental conditions affecting the species, such as food supply

Results of Recent Modeling Efforts

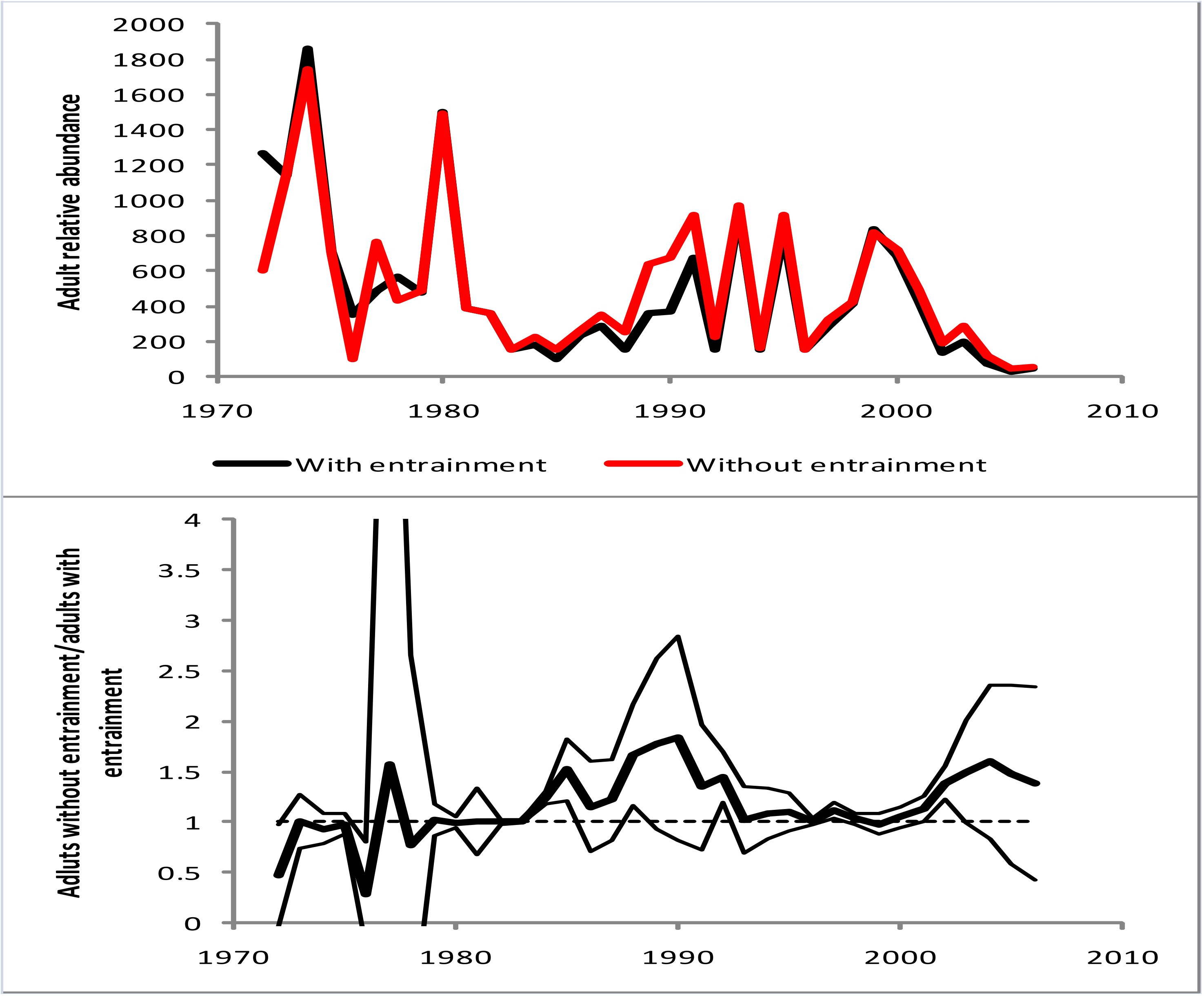
MacNally et al. (2010)	Thomson et al. (2010)	Maunder and Deriso (2011)	Miller et al. (2012)
Factors with statistically significant effects			
Predator abundance		Predator abundance	Predator abundance
Summer temperatures		***Water temperatures***	Water temperatures
		Prey density	***Prey density***
Duration of water temperatures suitable for spawning			
	Water clarity		
	Winter exports		

Bold italic = Strong effect
Regular = Weak effect

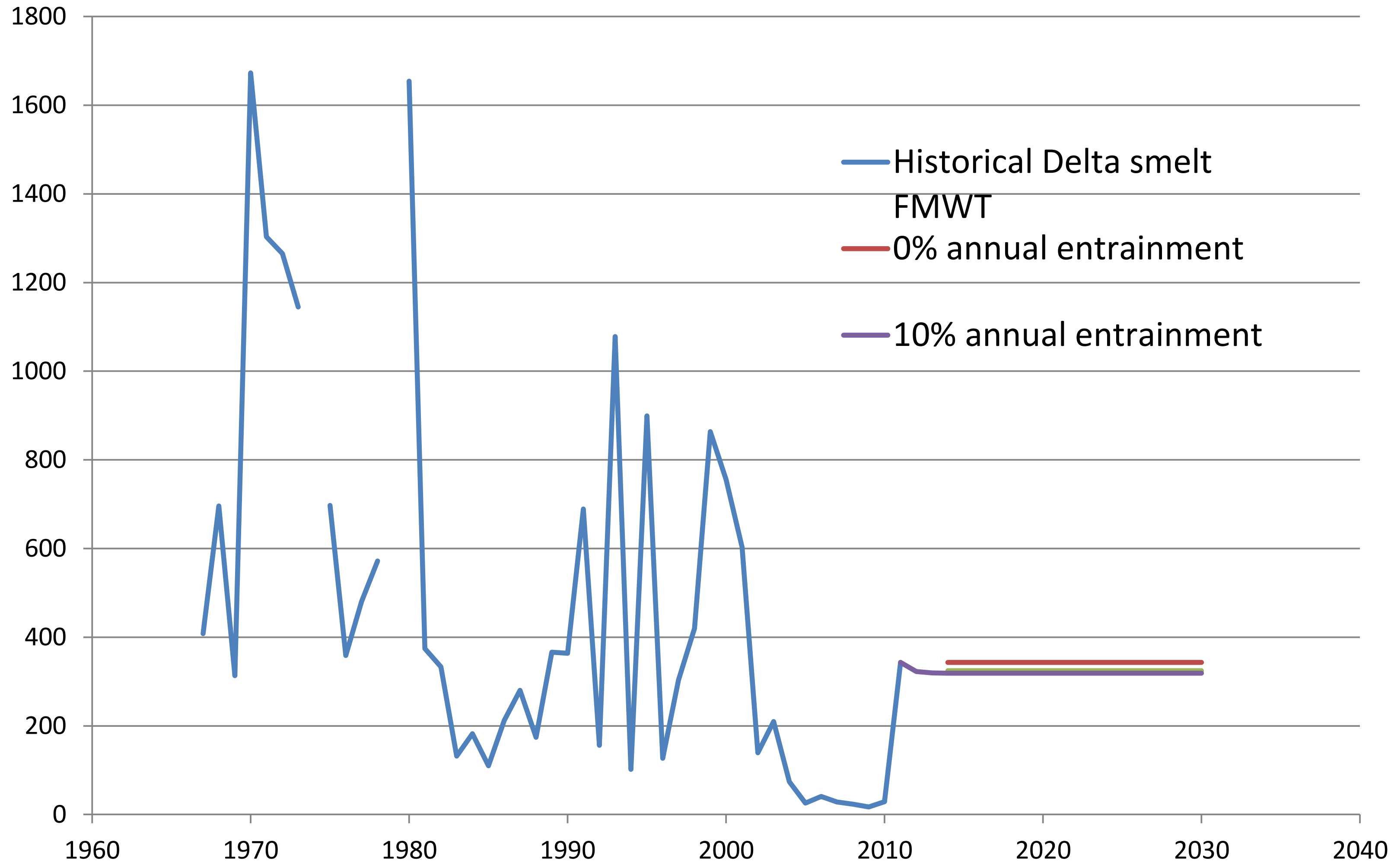
Results of Recent Modeling Efforts

MacNally et al. (2010)	Thomson et al. (2010)	Maunder and Deriso (2011)	Miller et al. (2012)
Factors without statistically significant effects			
Spring X2	Spring X2	Spring X2	Spring X2
Fall X2	Fall X2	Fall X2	Fall X2
		Juvenile entrainment	Juvenile entrainment
		Adult entrainment	Adult entrainment
Silverside abundance			
Water clarity			

Impact analysis: entrainment



Historical and Possible Future Steady State Delta Smelt FMWT Values

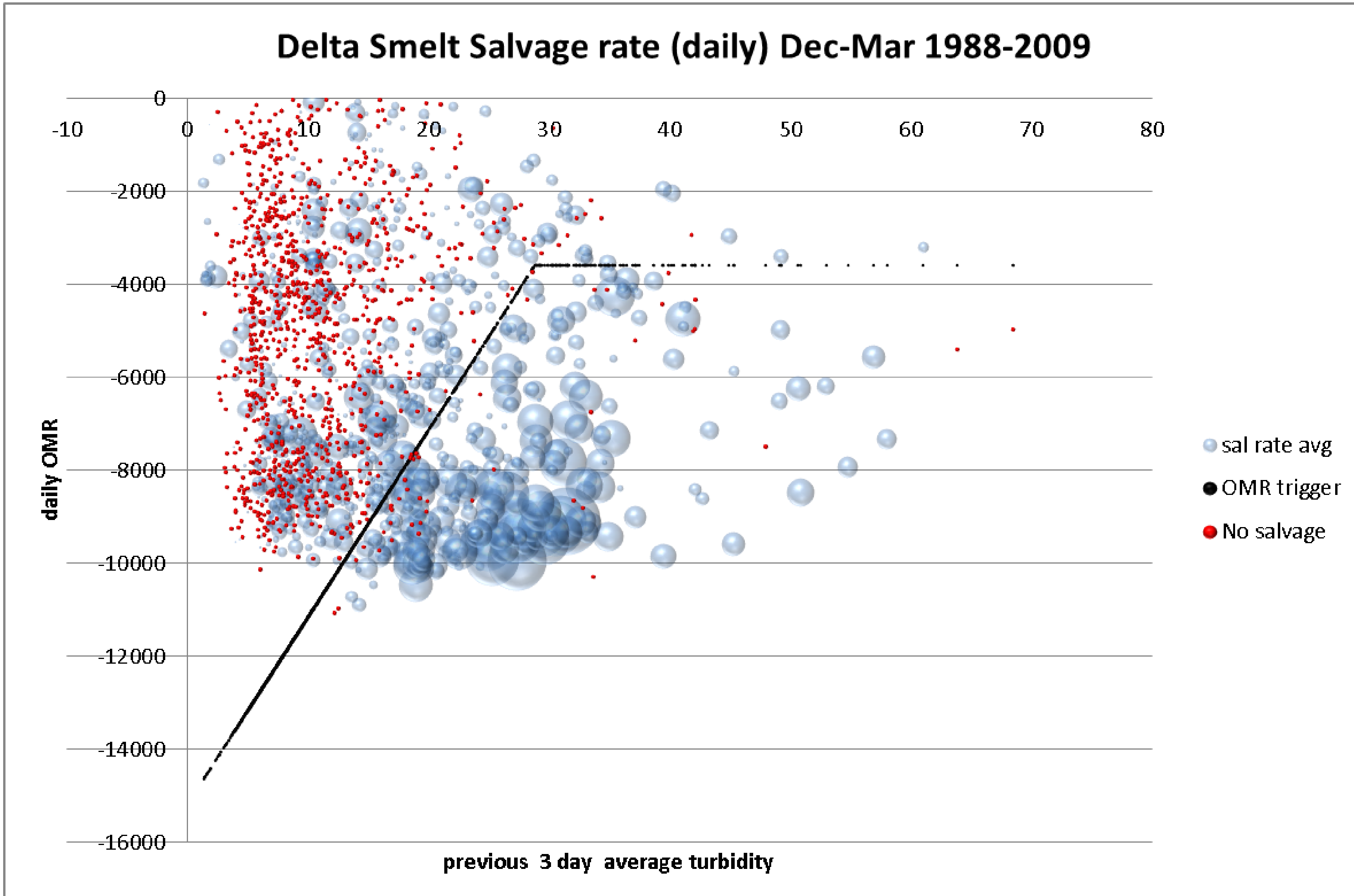


Management of Adult Smelt Entrainment

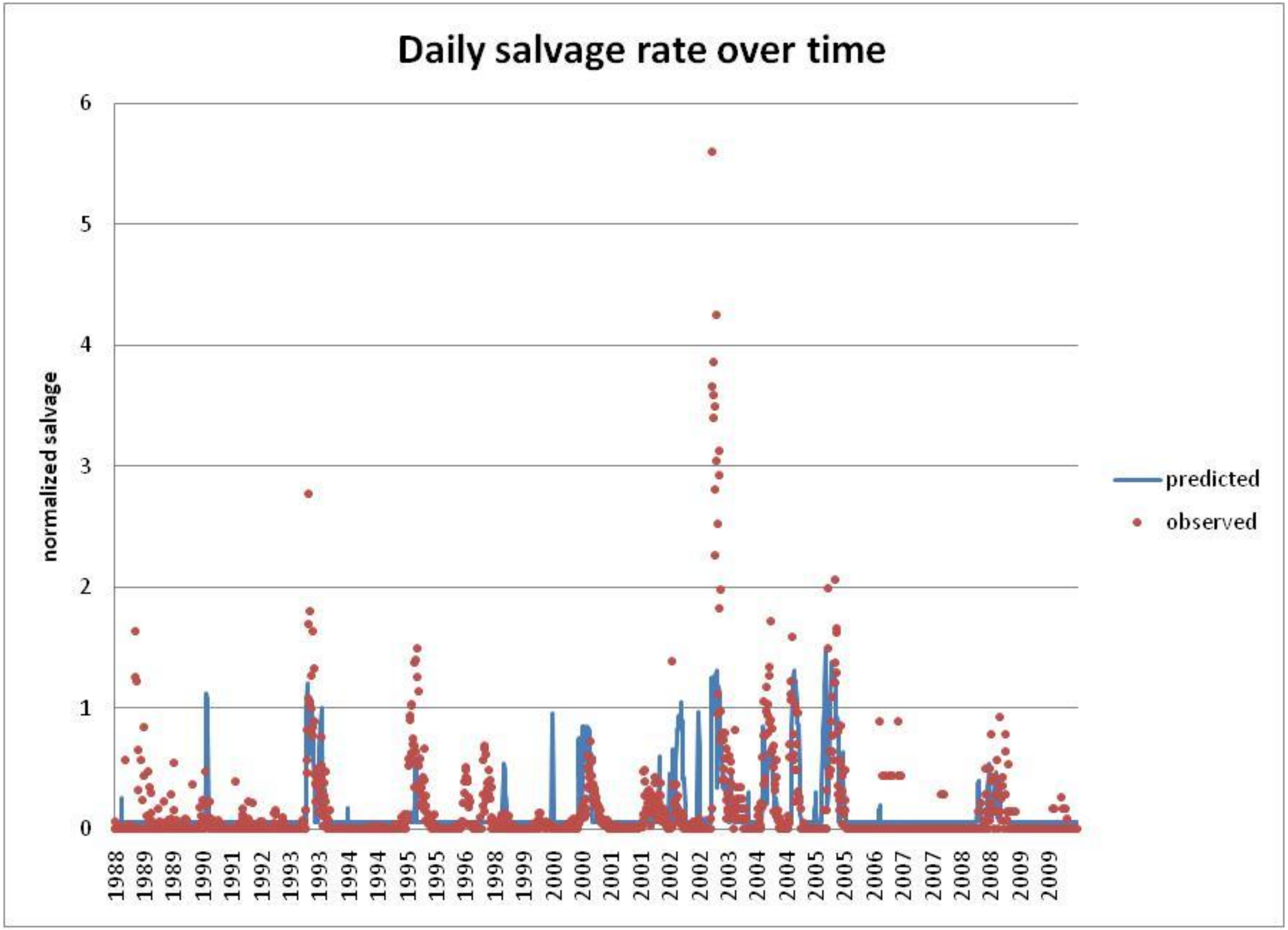
Turbidity Can be Used to Manage Entrainment

- Data show historic relationship between turbidity, OMR flow, and adult smelt entrainment
- Developed mathematical model as a function of turbidity at Clifton Court and OMR flow
- Model predicts adult salvage rates and when large entrainment events have occurred

Delta Smelt salvage rate as influenced by OMR and Clifton Court turbidity



Three-Day Turbidity OMR Model Predictions



Conclusions

- Entrainment does not appear to affect Delta smelt abundance patterns
- Entrainment levels are related to OMR and turbidity levels

Next up: Dr. Noble Hendrix, QEDA Consulting LLC

Delta smelt habitat and abundance

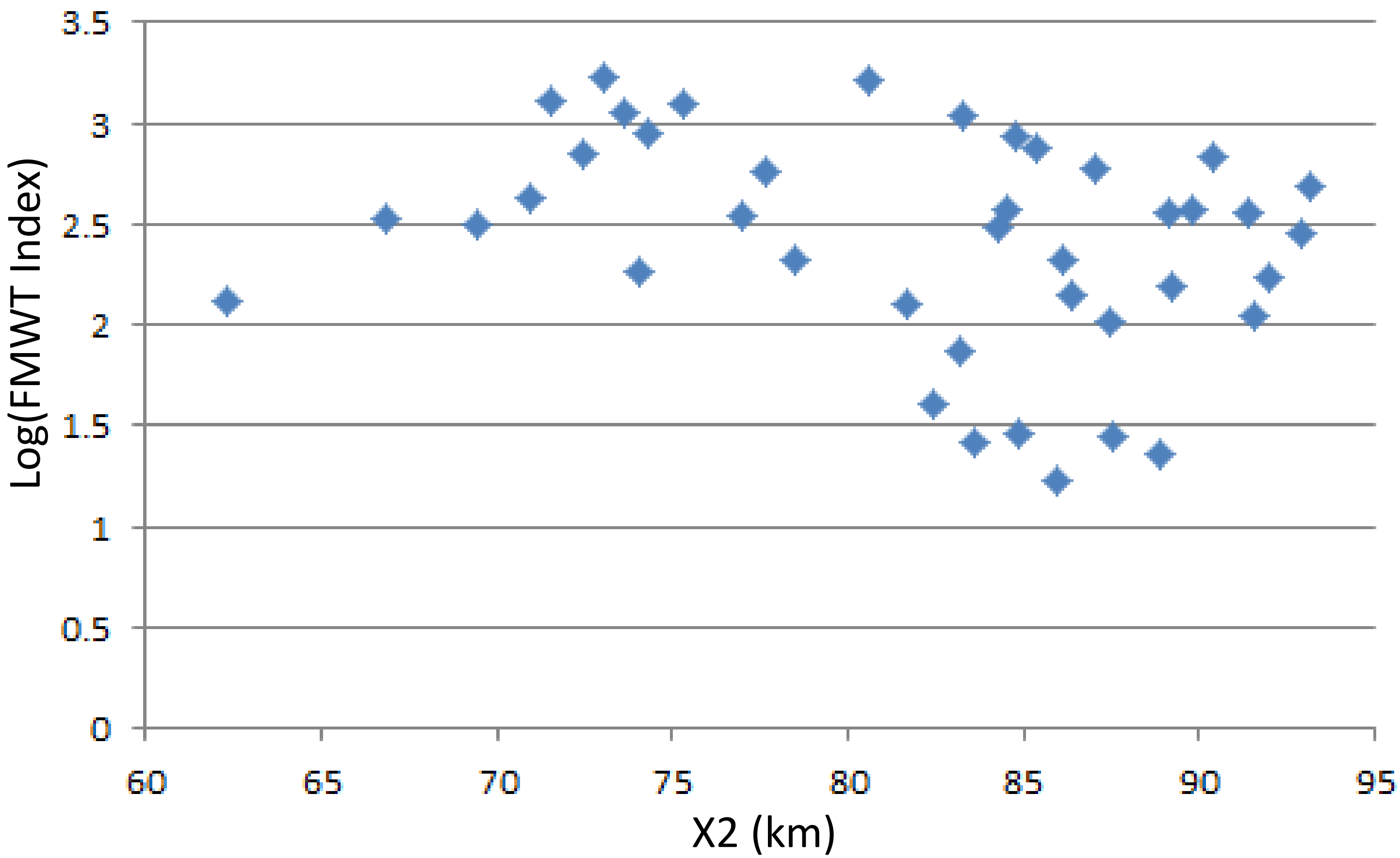
Fall X2 and Delta smelt abundance

Dr. Noble Hendrix

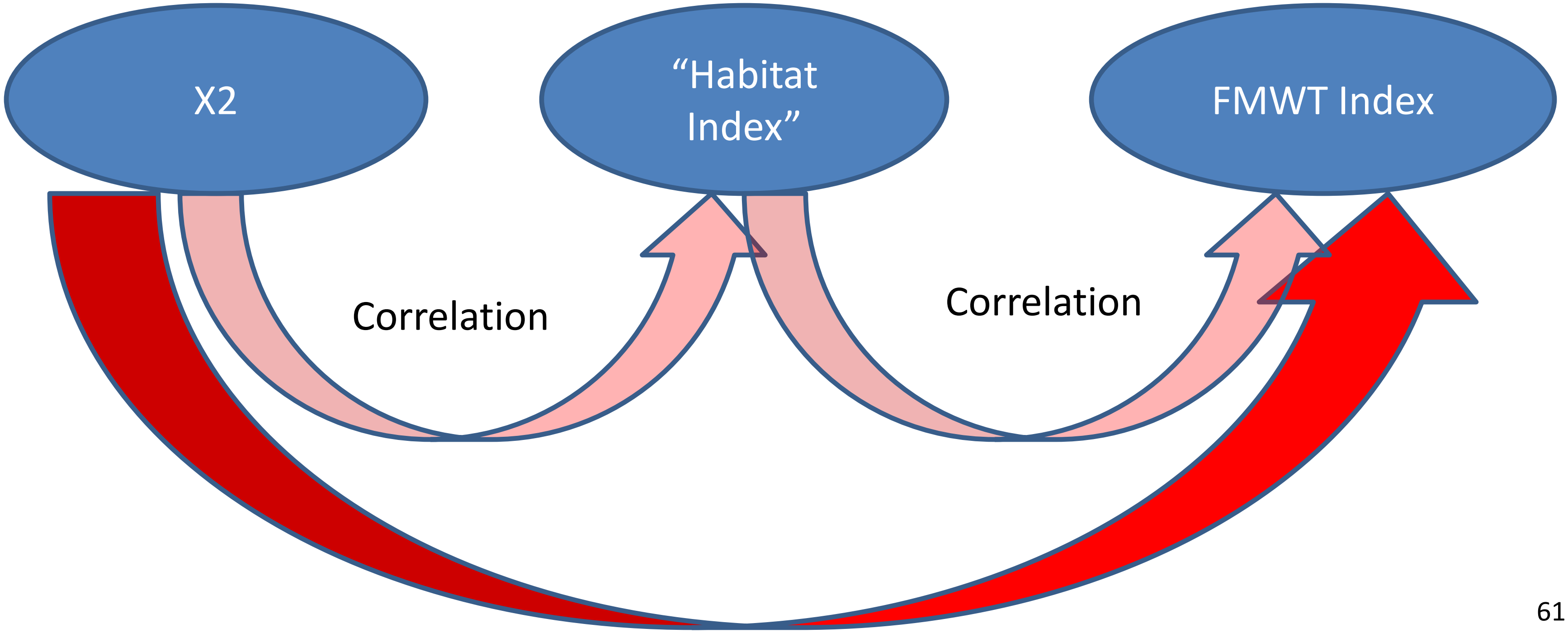
QEDA Consulting, LLC

10/2/12

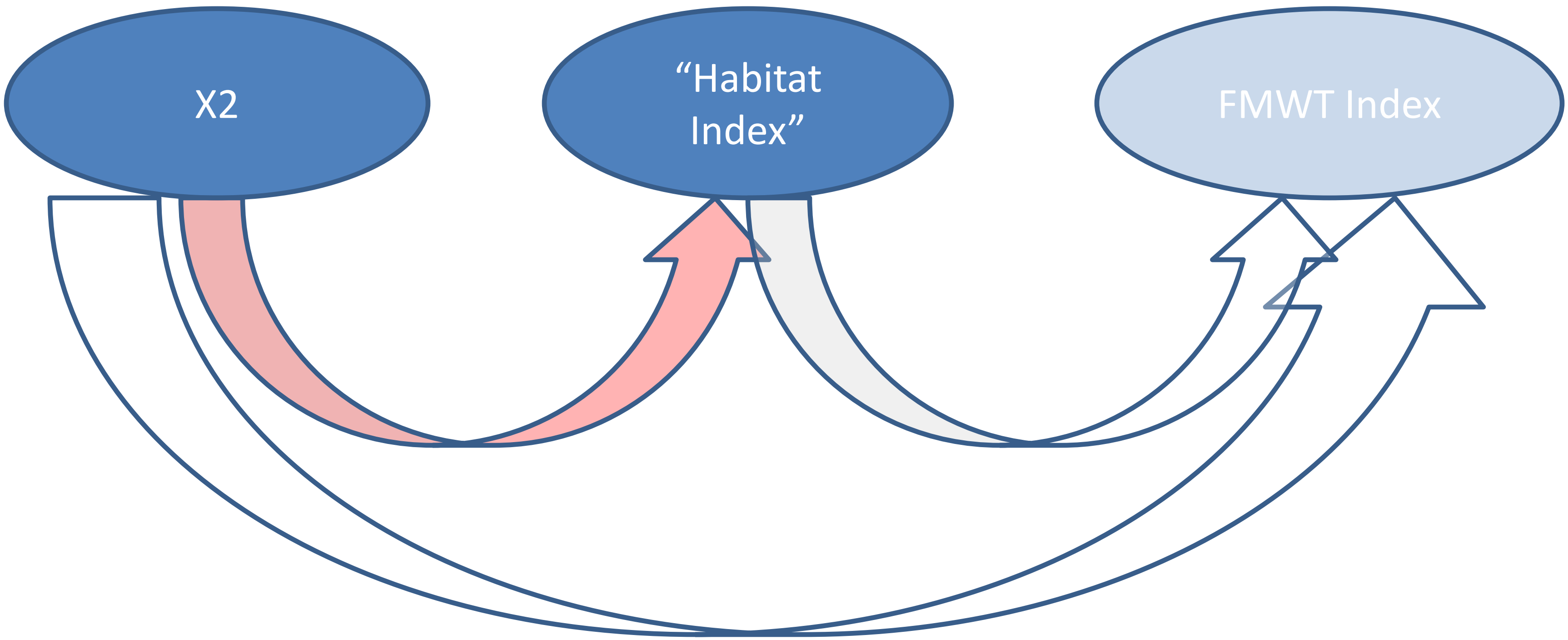
Correlation between delta smelt FMWT Index and Concurrent Fall X2



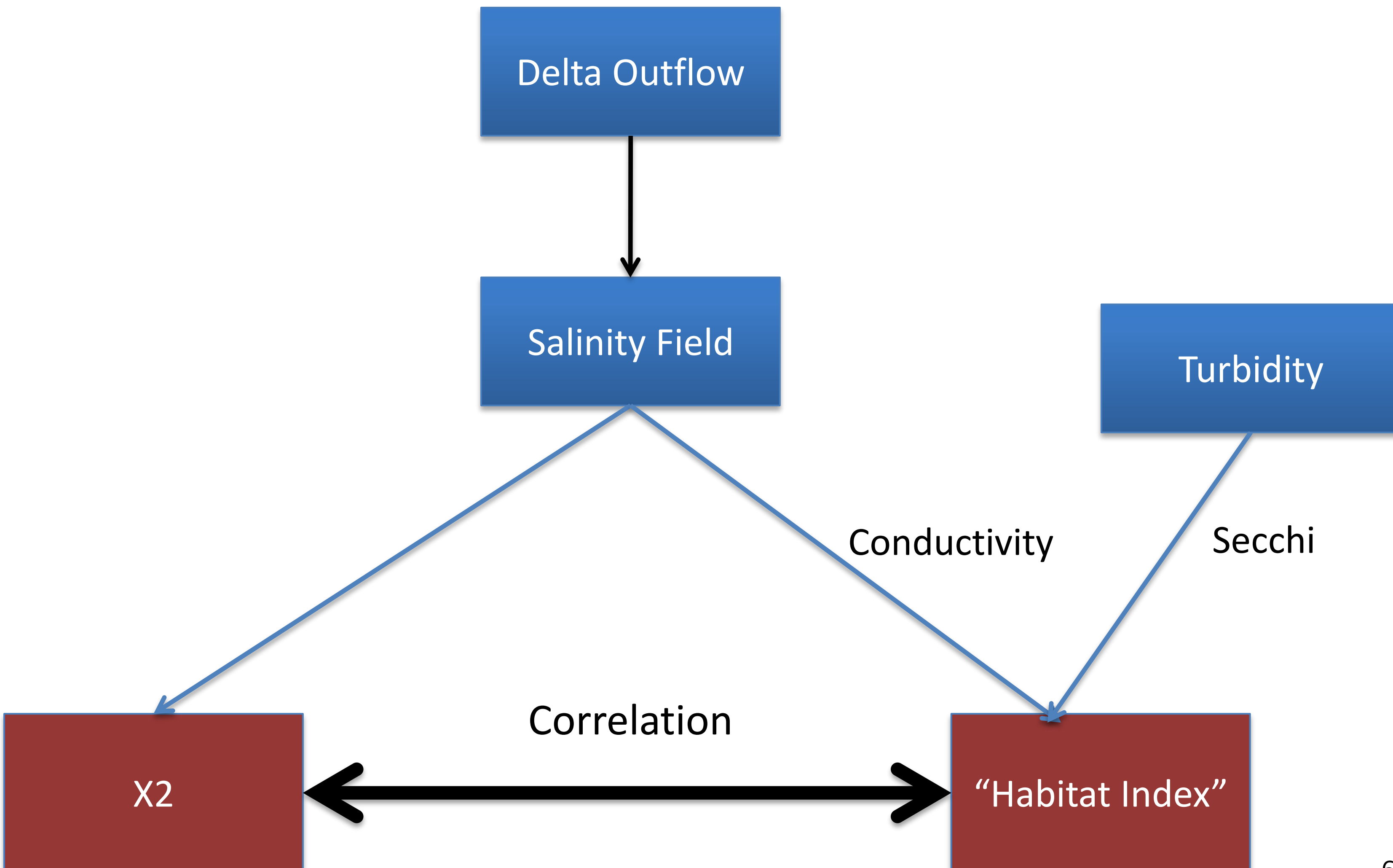
- Hypothesis of Feyrer et al. (2011):
  - X2 influences Delta smelt “Habitat Index”
  - Delta smelt “Habitat Index” influences Delta smelt abundance
  - Therefore, X2 influences Delta smelt abundance



X2 influences “Habitat Index”



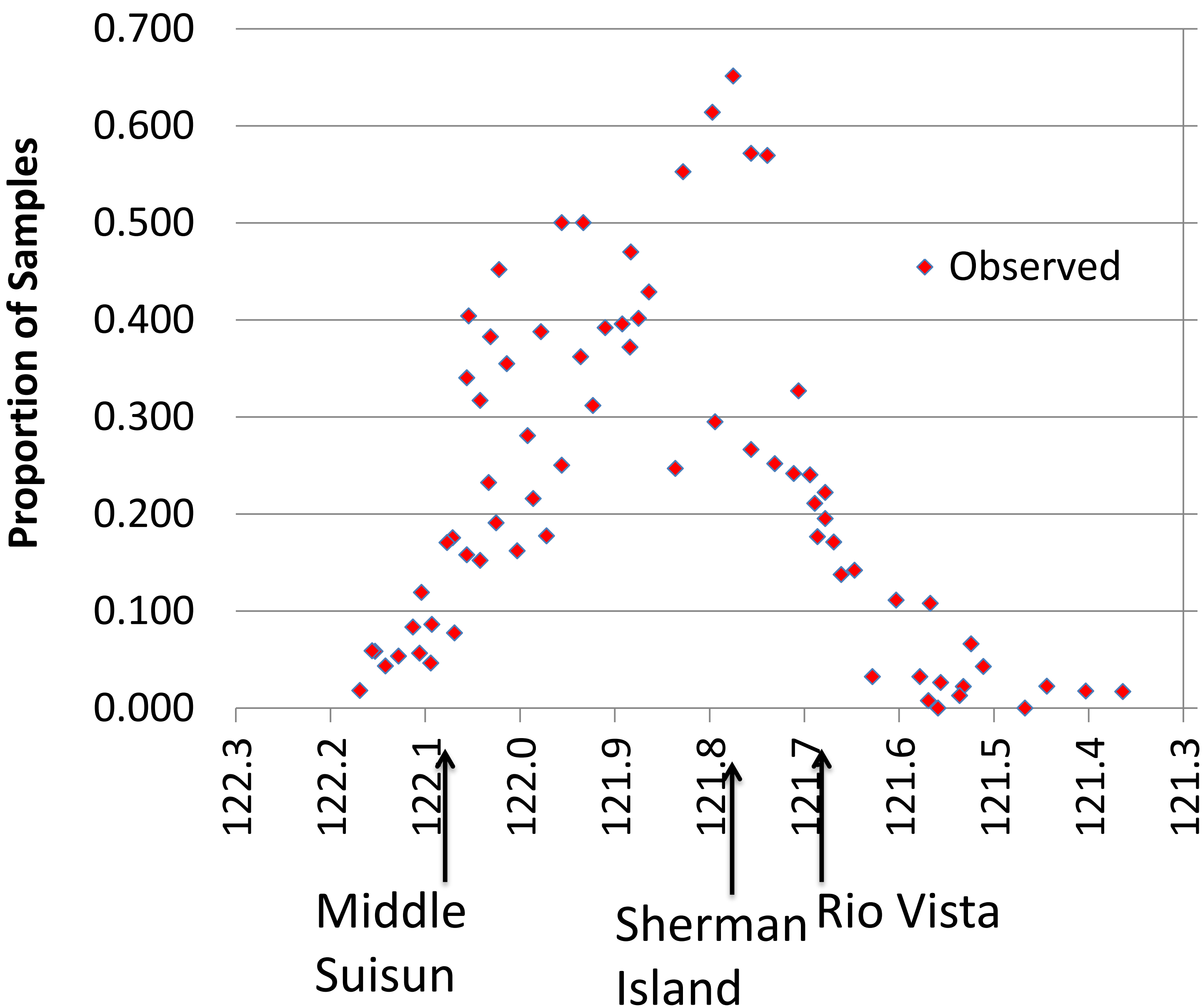
Using two measures of salinity (X2 and EC) assures X2 will correlate with “Habitat Index”



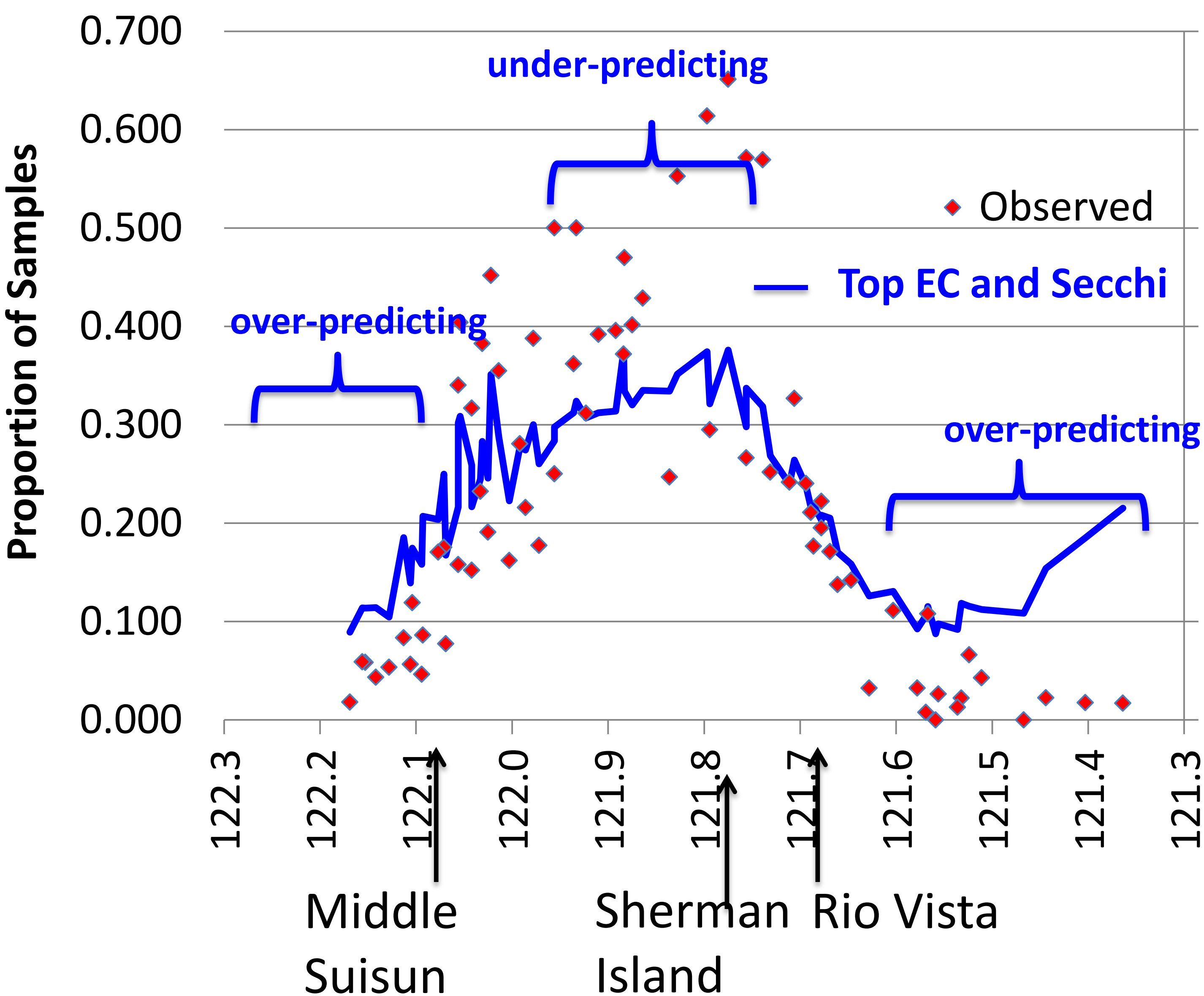
Other “Habitat Indices” fit the FMWT presence/absence data better

Model	% Variation explained	Correlation with X2
Top EC and Secchi	17.8%	-0.86
Longitude & Date	18.4%	-0.48

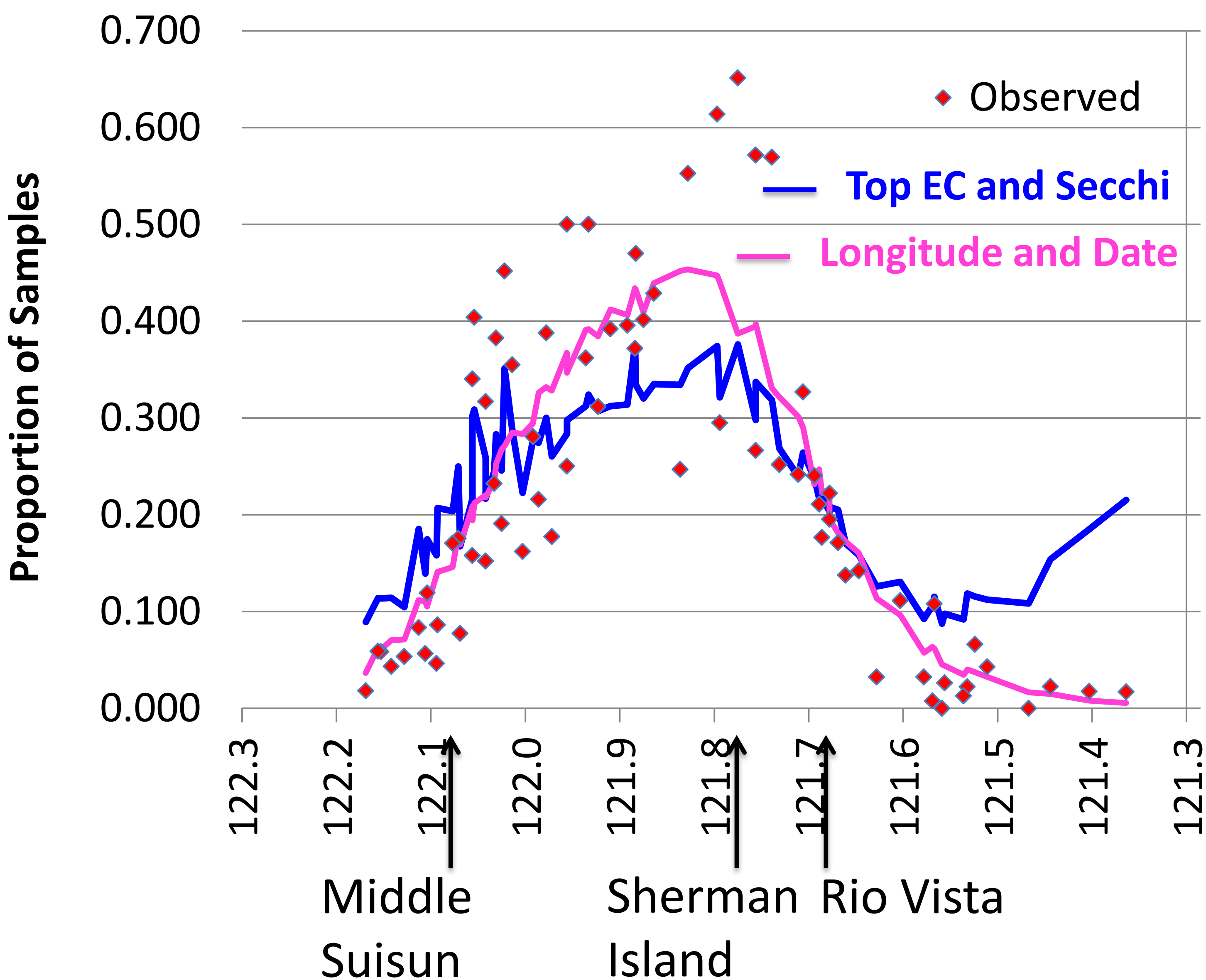
Proportion of samples with delta smelt



The "Habitat Index" does not fit well



Longitude model does better

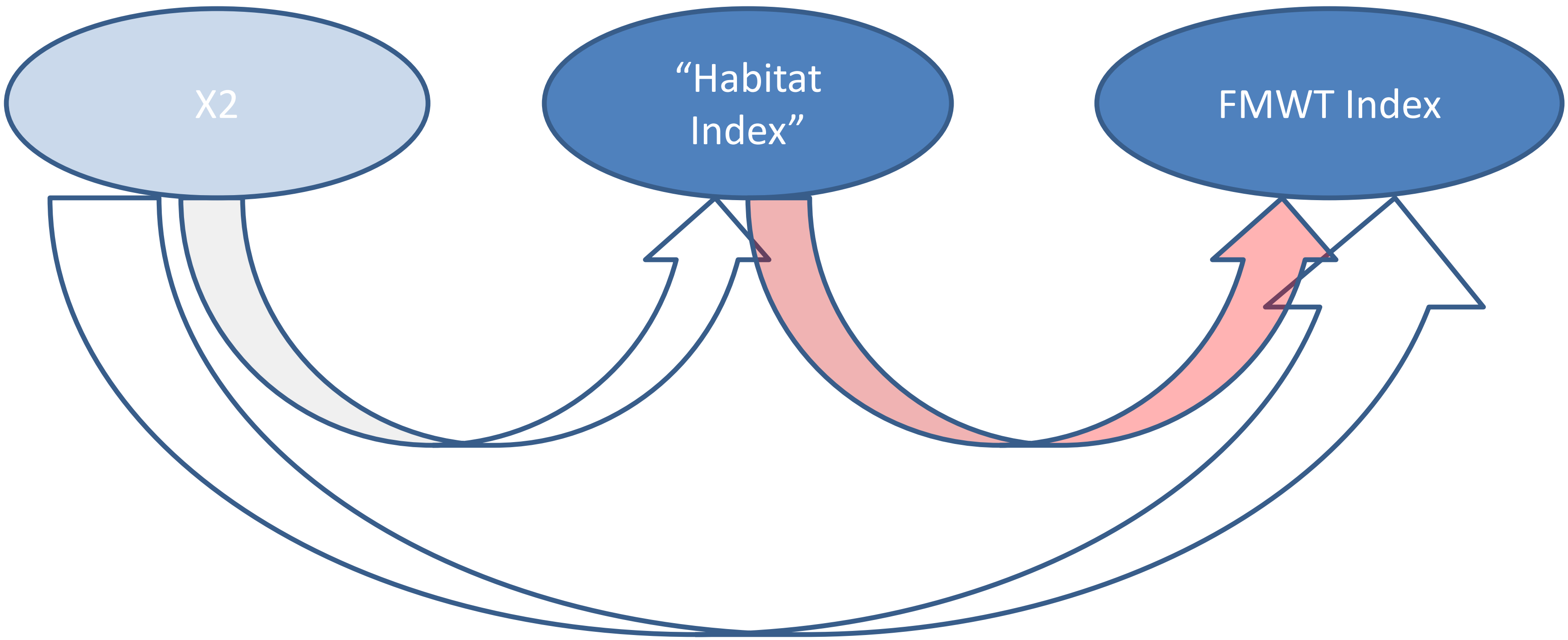


Low Salinity Zone and Estuarine Habitat

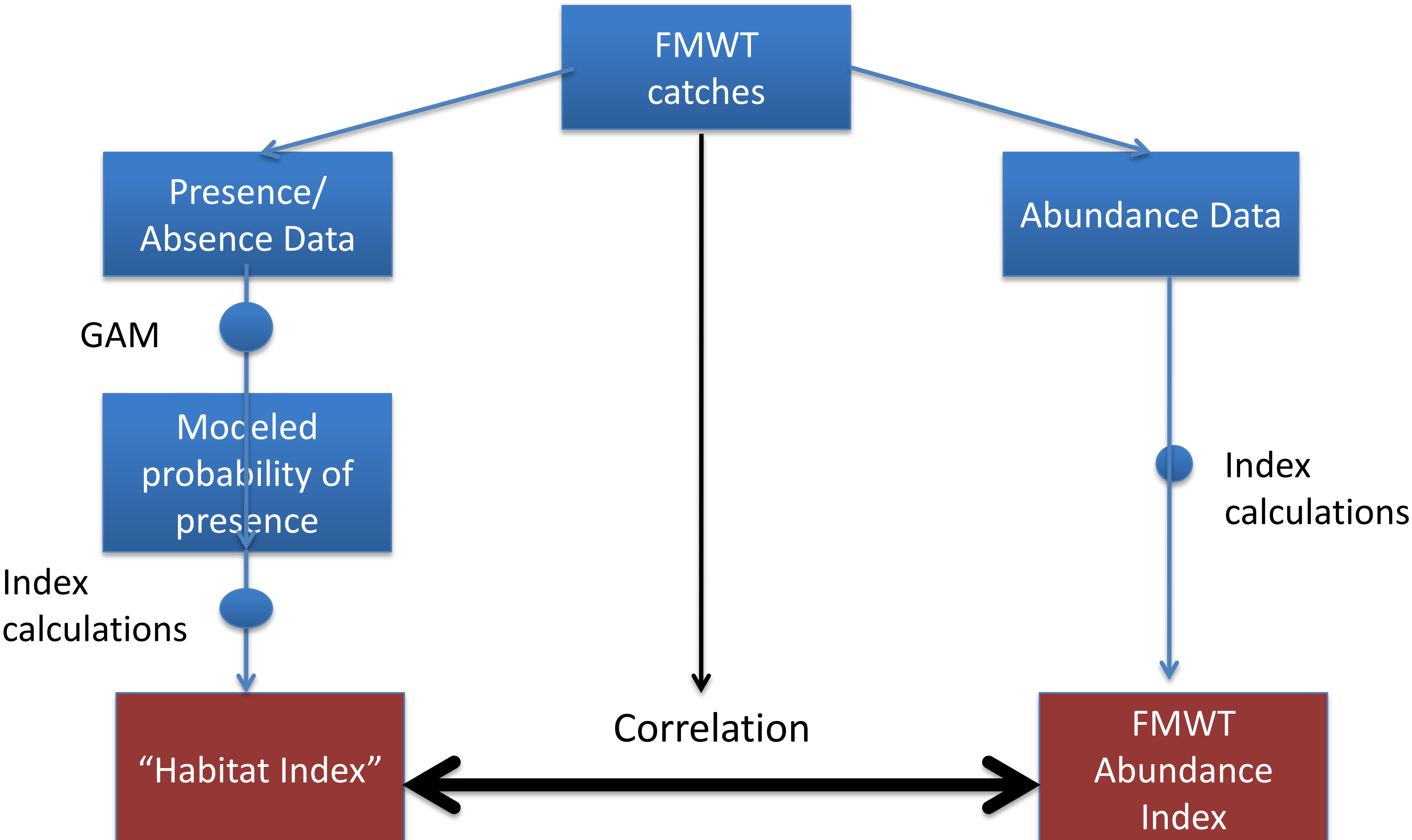
The low salinity zone (LSZ) is not equivalent to estuarine habitat. Estuarine habitat encompasses the range from 0 to 35 ppt salinity and the LSZ is just one part of the overall gradient. Other gradients and important aspects of habitat in this estuary include: salinity, temperature, turbidity, food supply, predation, connectivity, geometry, variability [in time and space].

- USEPA Technical Workshop Summary

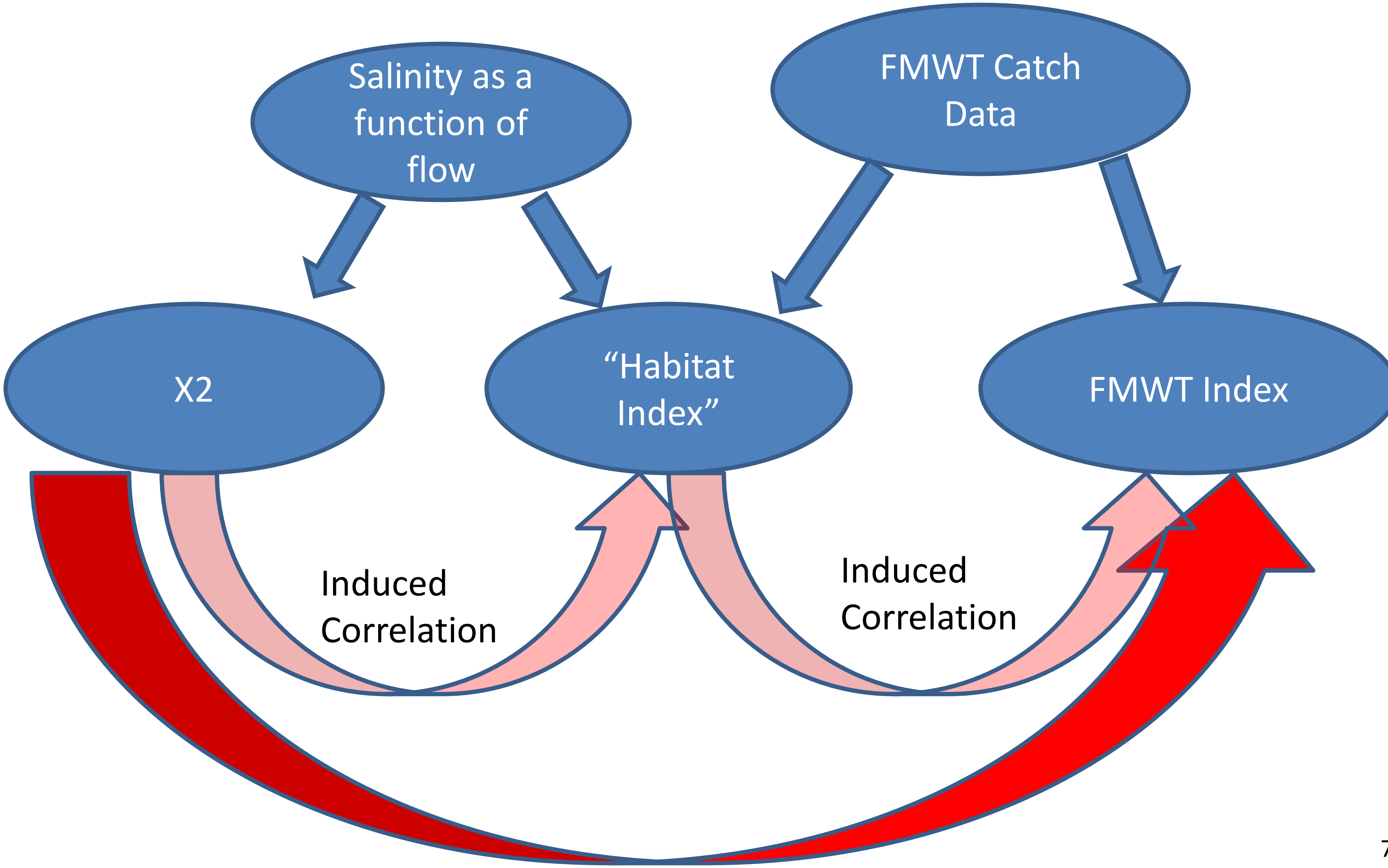
“Habitat Index” influences abundance



Construction of two indices from the same catch data ensures correlation



Result: Chain of Induced Correlations



What USFWS Says About Induced Correlation

Feyrer et al. (2011) showed that despite being based on presence or absence of delta smelt, their resultant habitat index was correlated with the FMWT abundance index… However, this is an expected outcome because delta smelt abundance and presence-absence are correlated. The point in showing this association was to demonstrate that although the linkage is variable and inherently based on a circular argument (because catch was used to define habitat suitability), there is nonetheless a correlation between the FMWT indices and the habitat indices, which are nonlinearly related to fall X2.

USFWS Workshop #1 page 46.

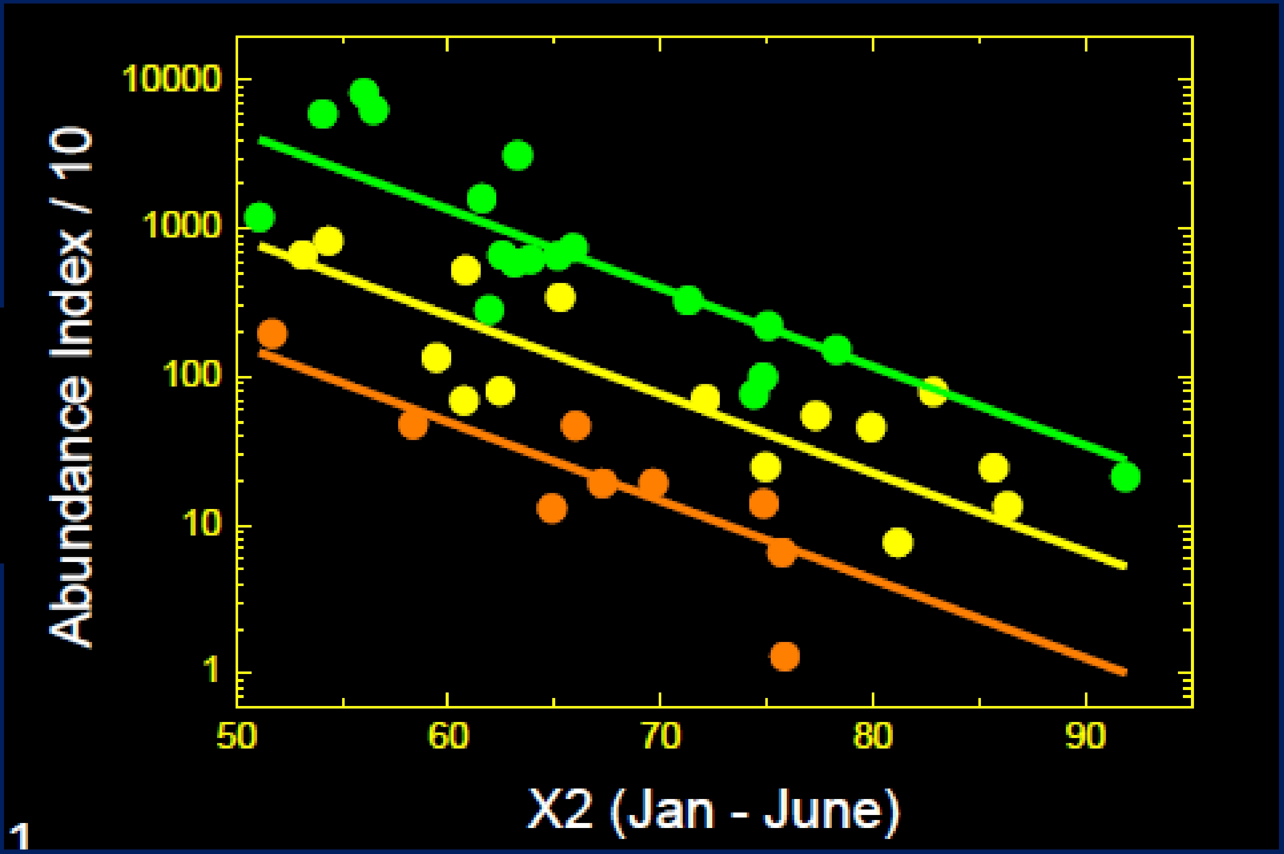
Conclusions

- The circularity means that comparing the “habitat index” to the FMWT abundance will be meaningless – the “habitat index” is essentially being compared to itself
- The “habitat index” should reflect the spatial patterns in observed smelt distribution

Next up: David Fullerton, MWD
Longfin smelt

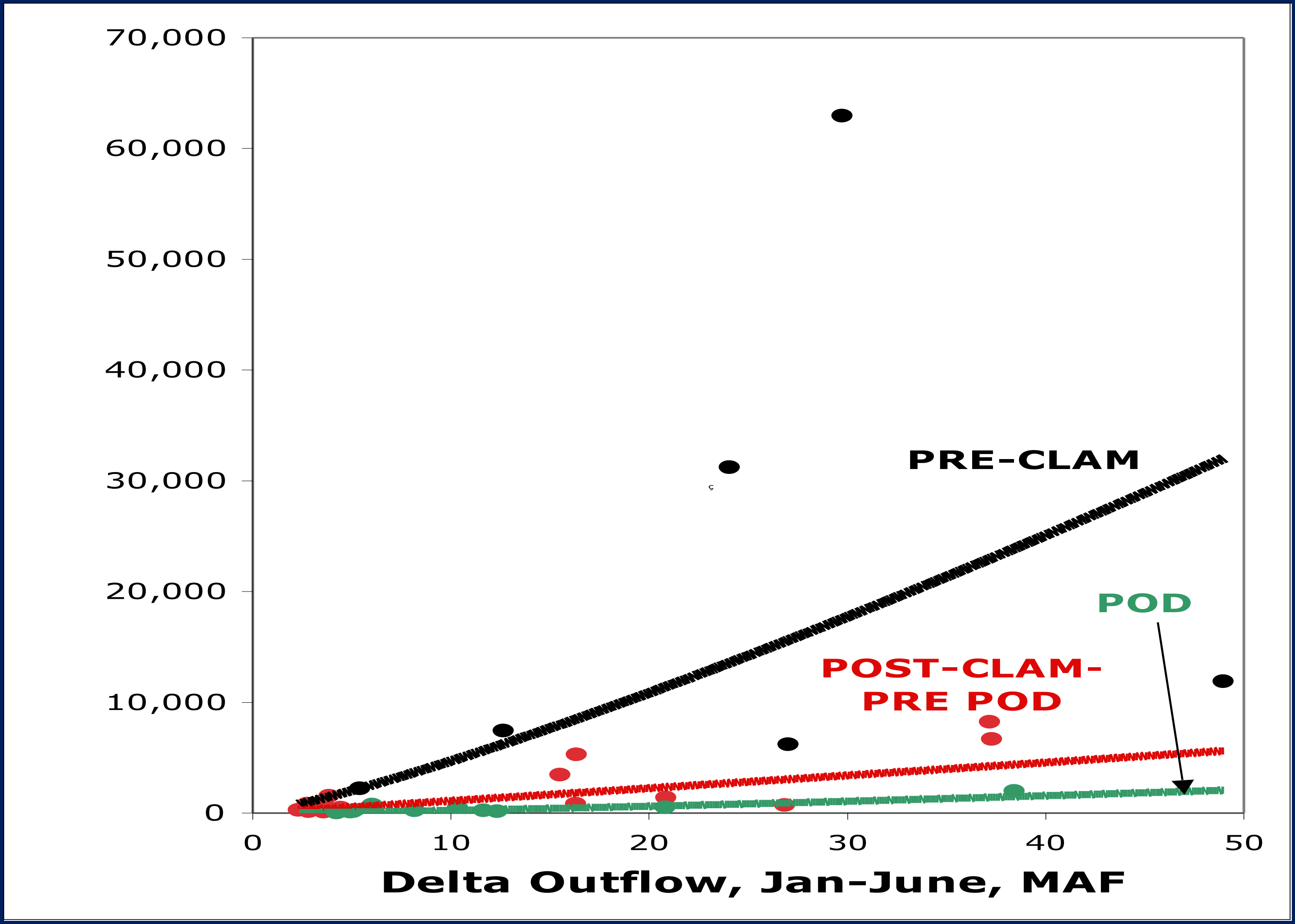
Longfin:X2 Relationship

1967 – 1987: Pre-clam
1988 – 2002: Post-clam
2003 – 2011: Post-POD



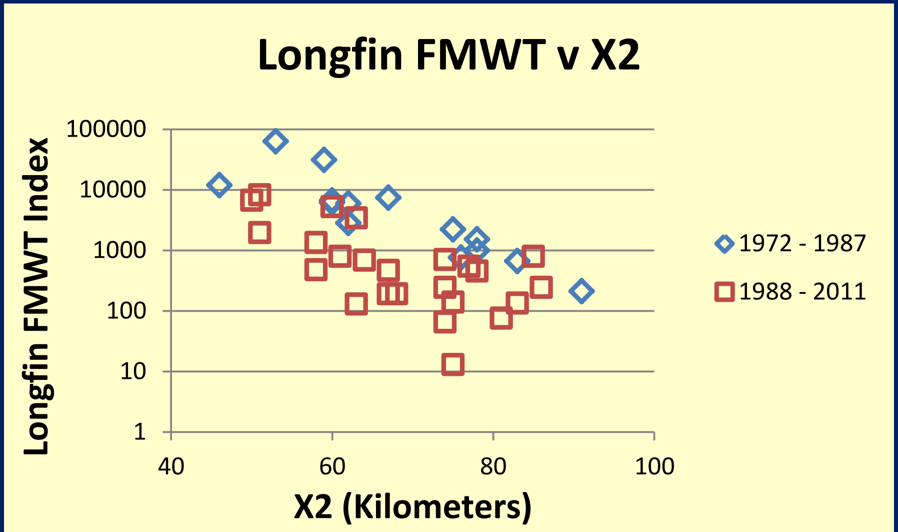
Expert Panel Presentation, Workshop 1

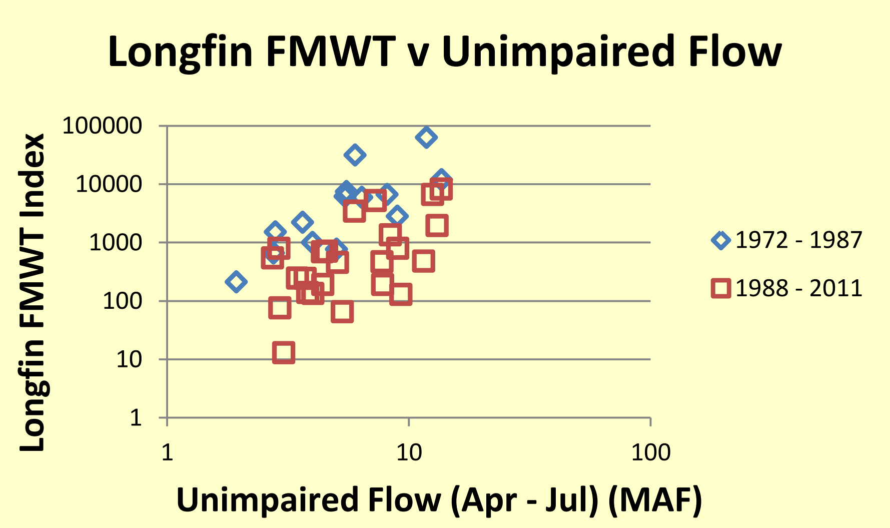
The FMWT: Flow relationship is now nearly flat

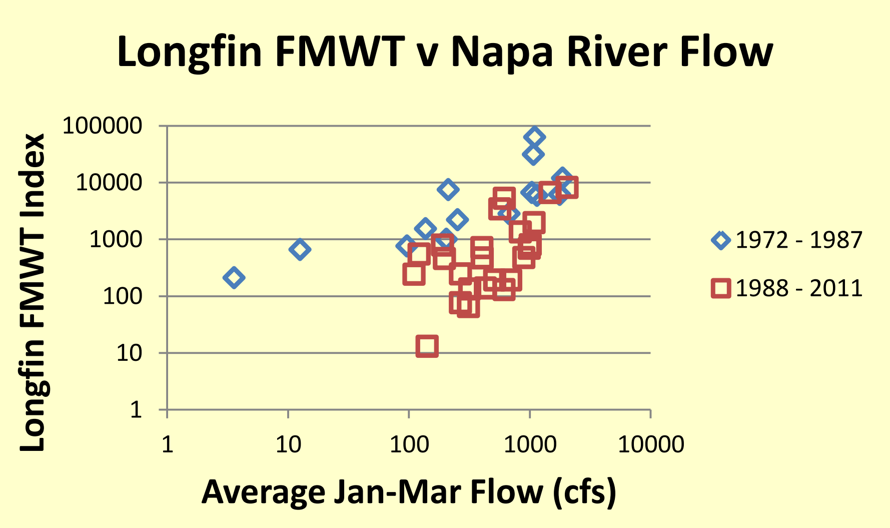


Source: FMWT Index and Dayflow

Flow:Abundance Relationships

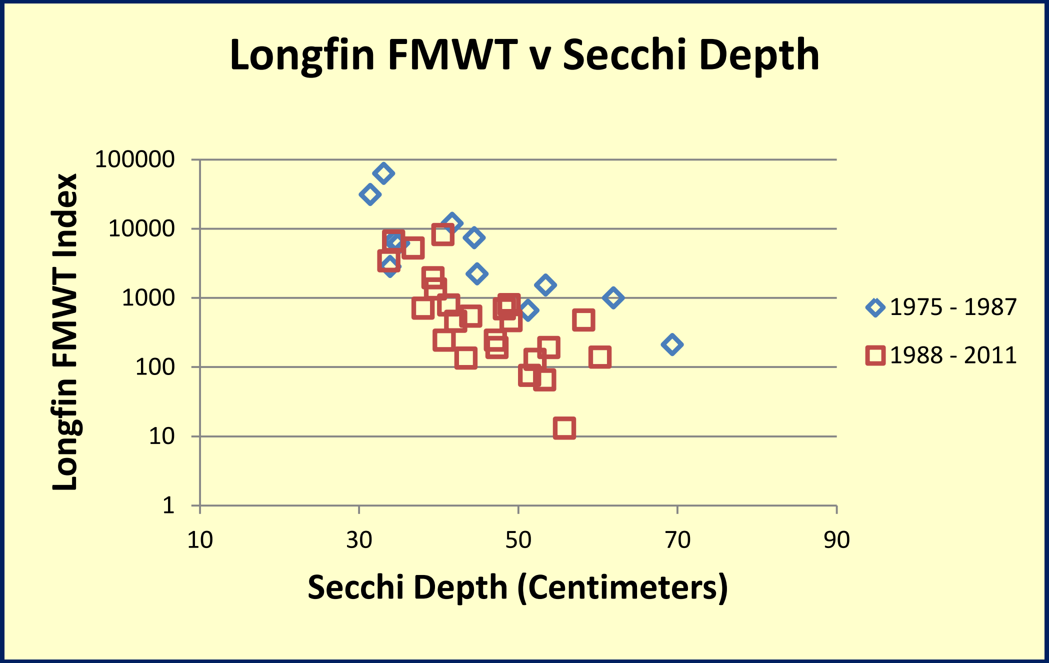


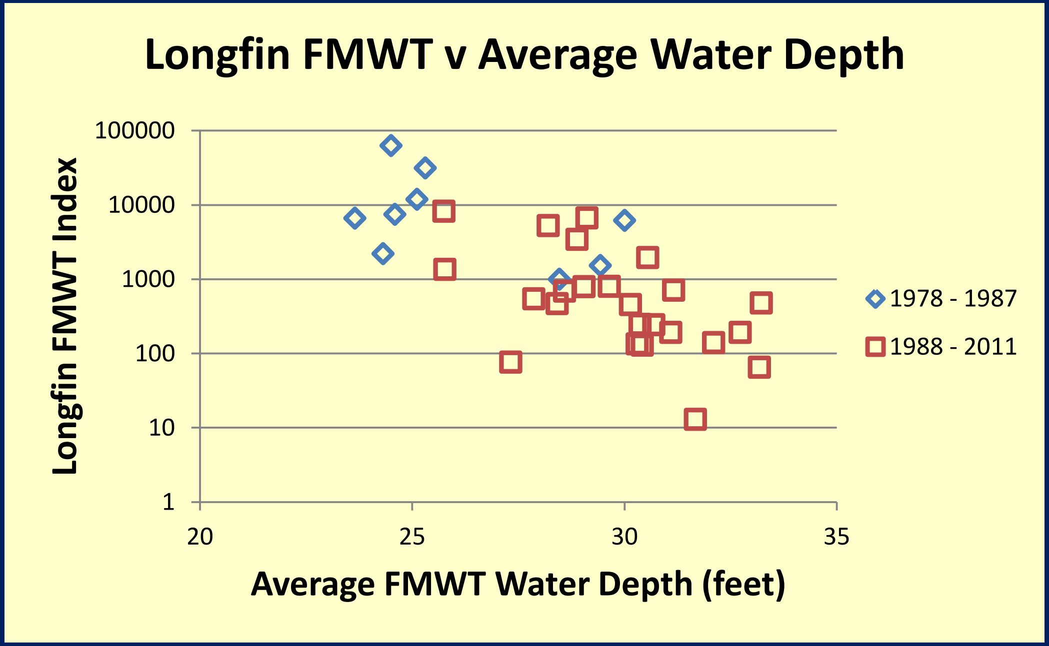




Source: DWR

Source: USGS

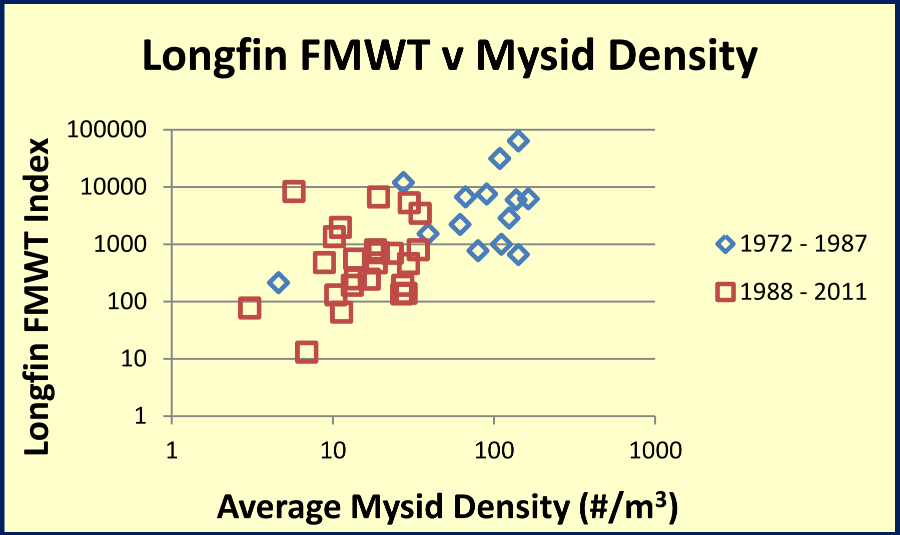


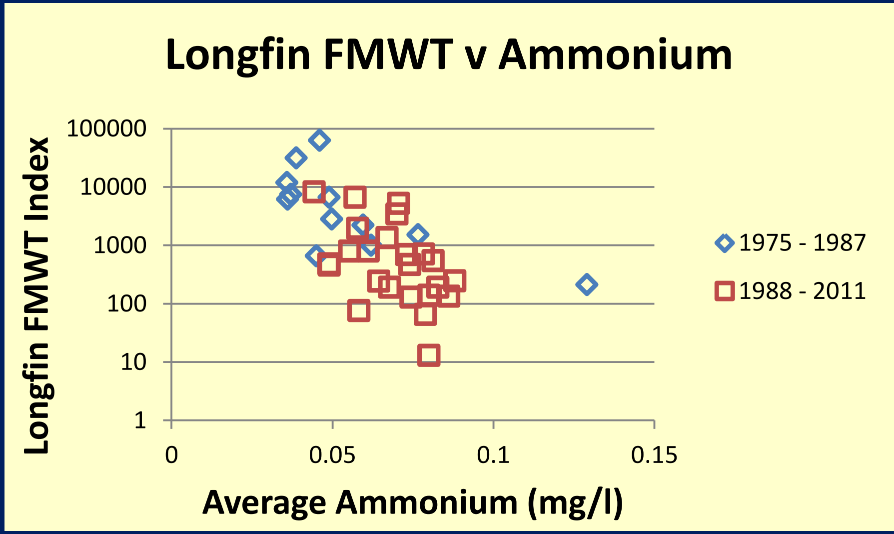


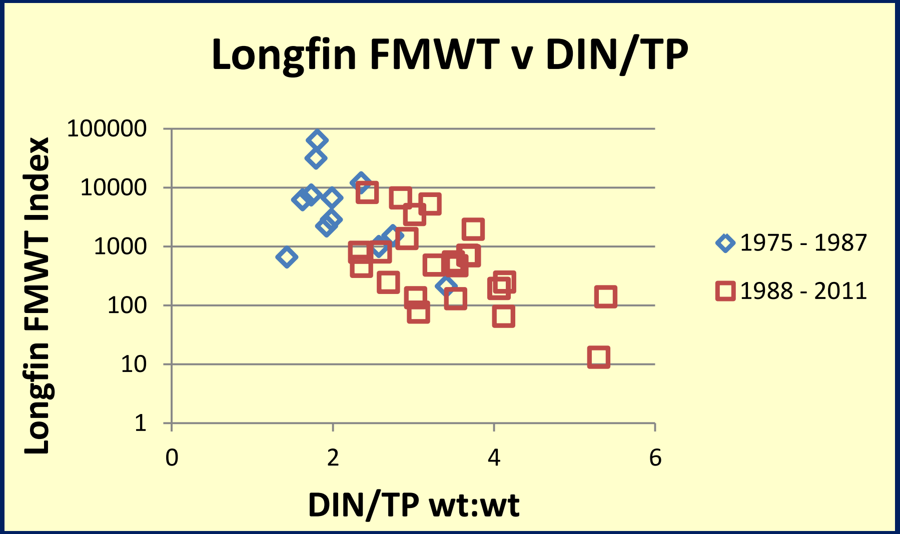
Water Depth, Secchi Depth :Abundance Relationships

Source: EMP

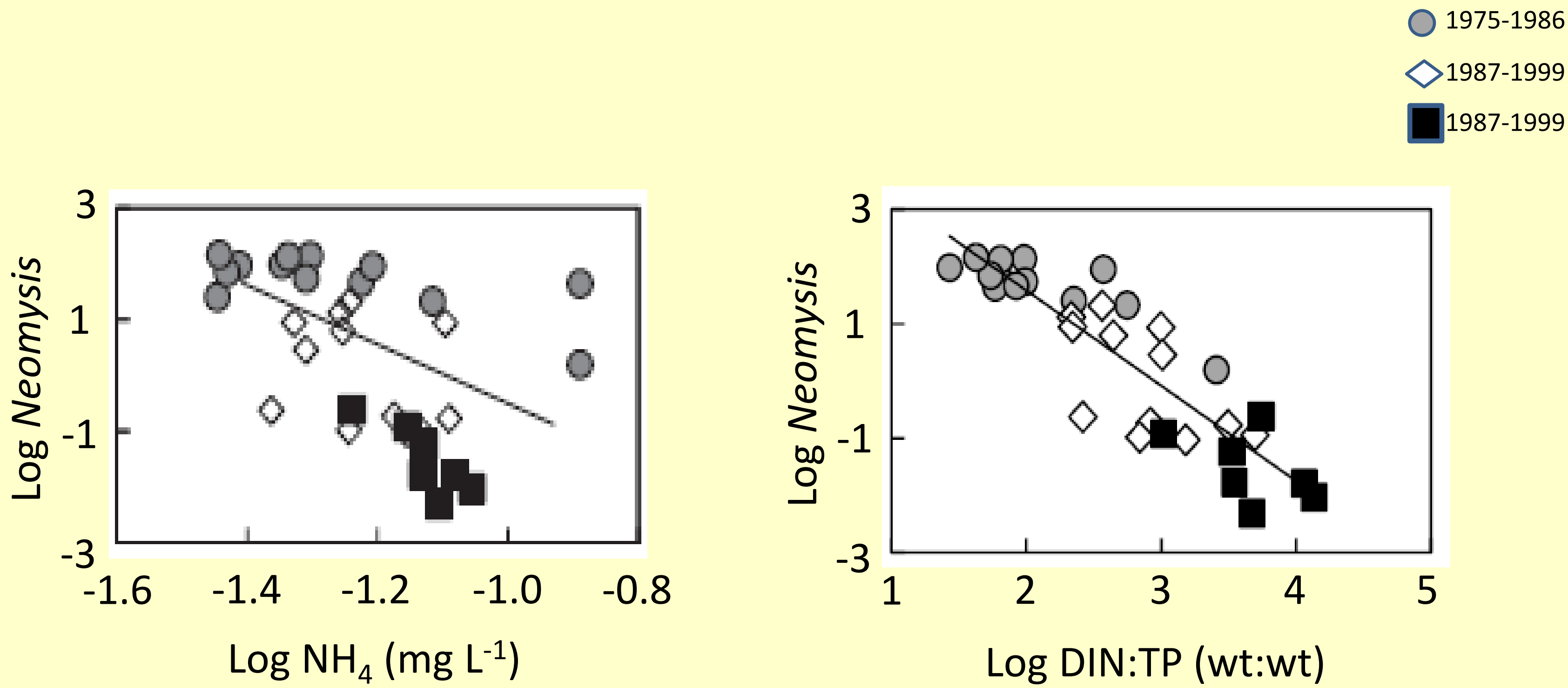
Nutrients/Food:Abundance Relationships



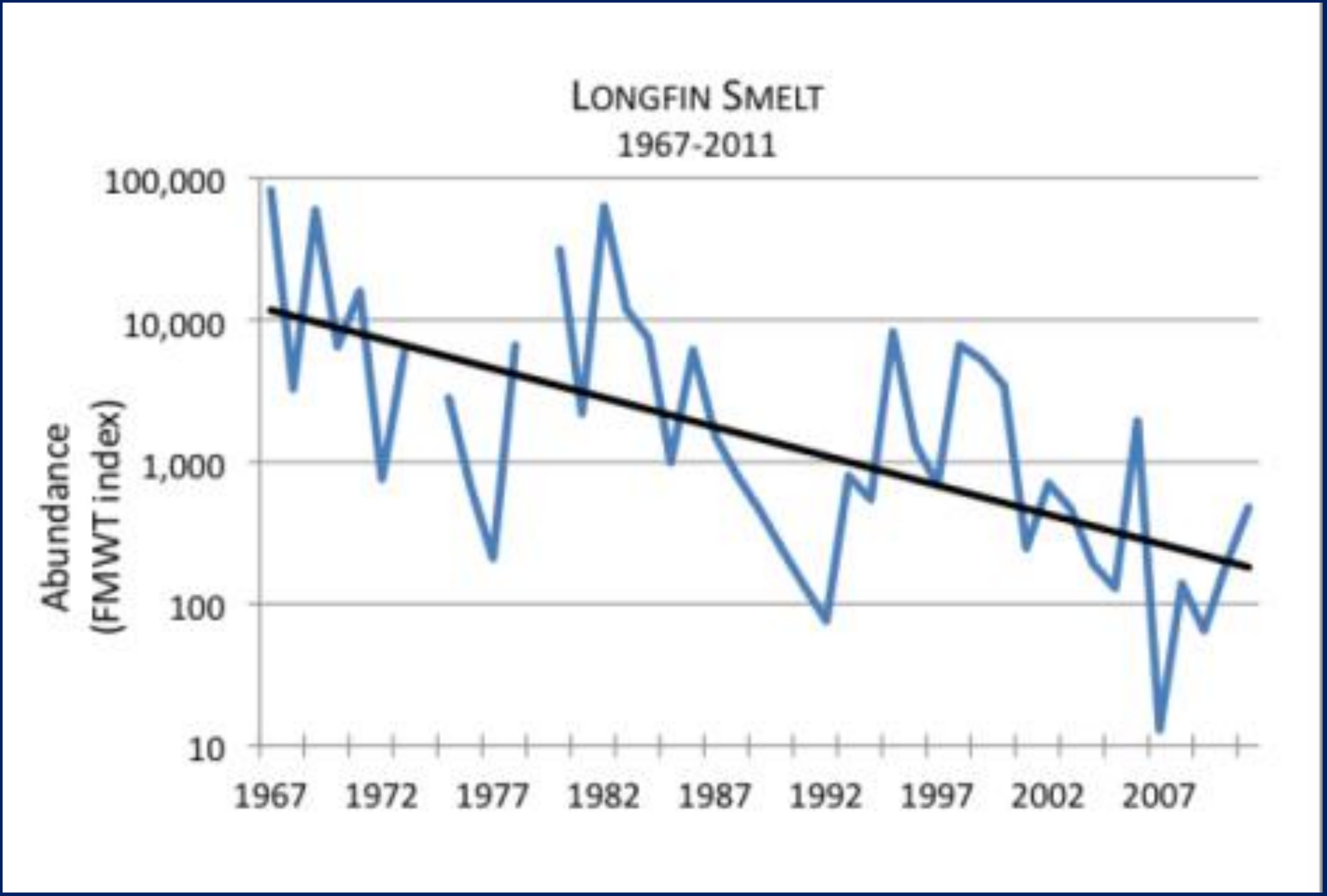




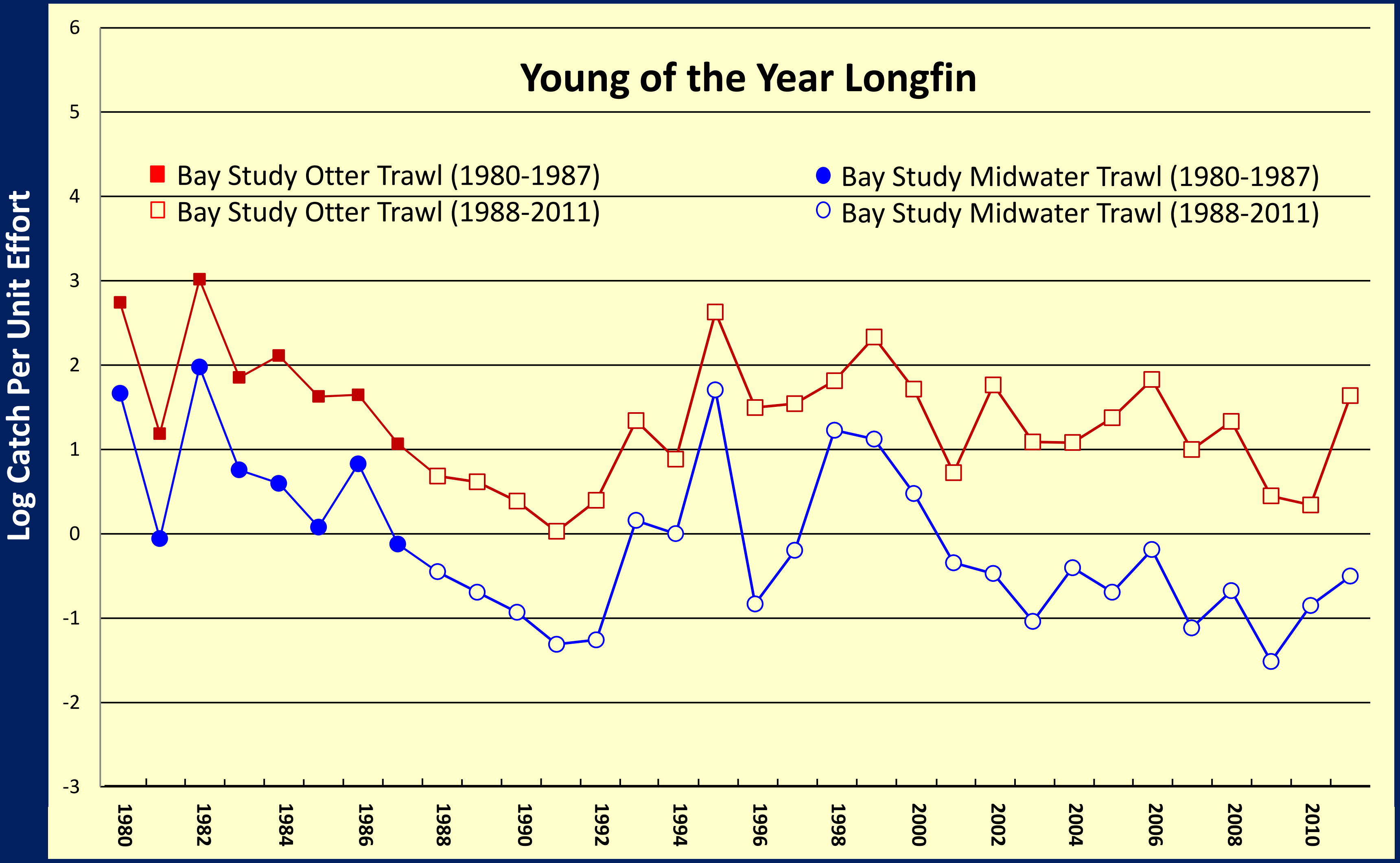
Nutrients:Abundance Relationships



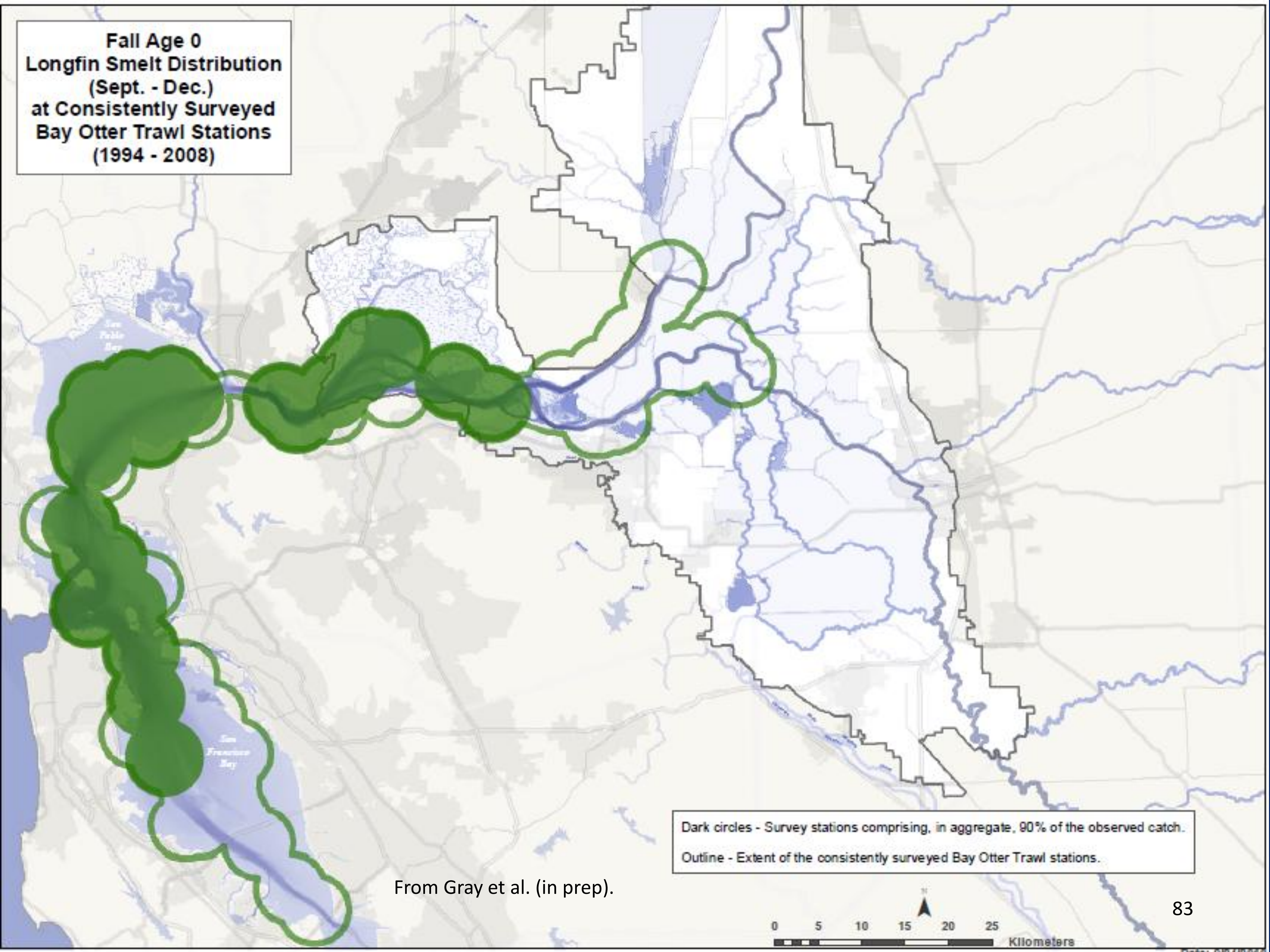
From Glibert et al. (2011)



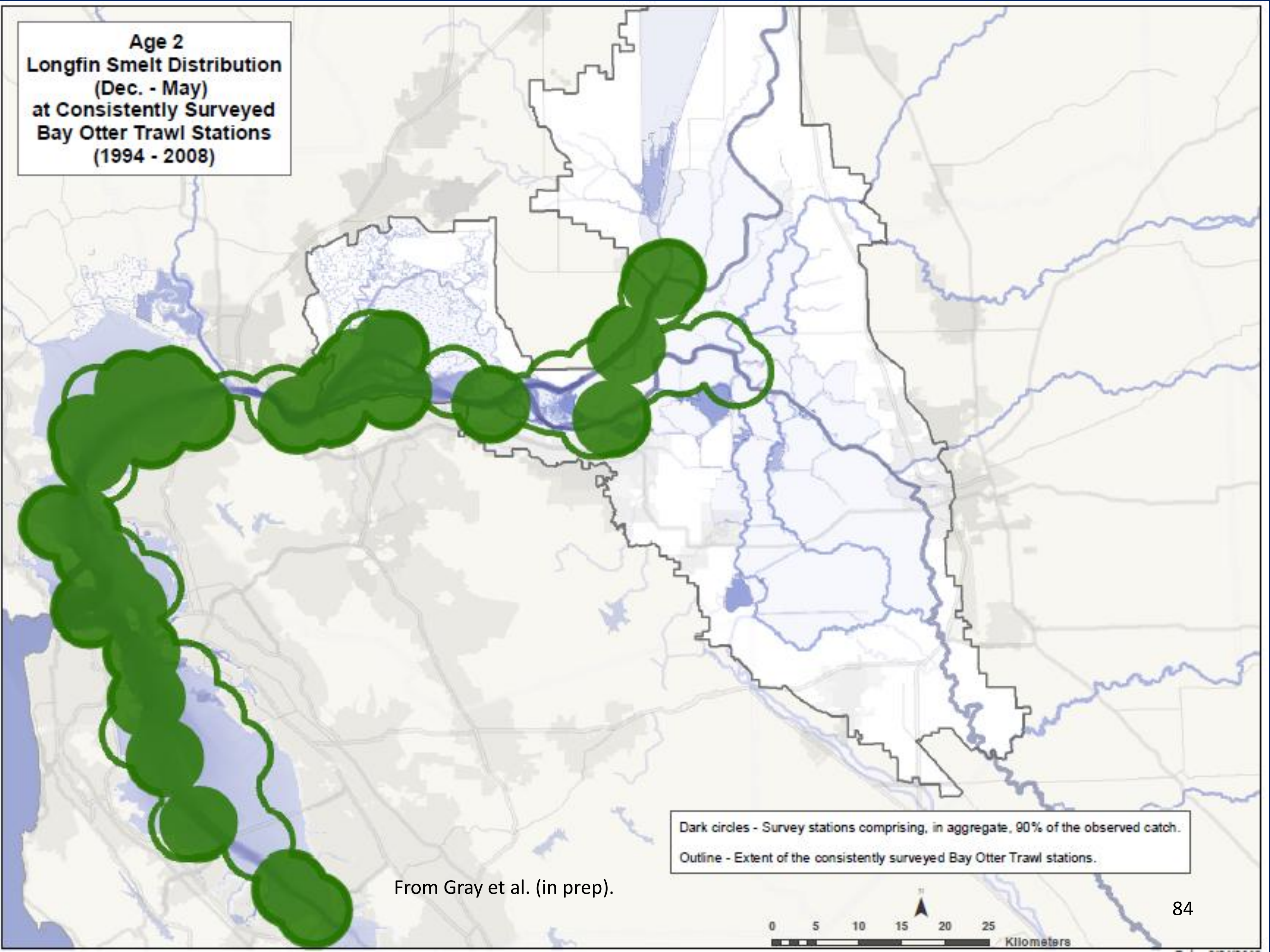
From Bay Institute presentation at Workshop 1, slide 7


Young of the Year Longfin
Bay Study Otter Trawl (1980-1987)
Bay Study Otter Trawl (1988-2011)
Bay Study Midwater Trawl (1980-1987)
Bay Study Midwater Trawl (1988-2011)
Log Catch Per Unit Effort
6
5
4
3
2
1
0
-1
-2
-3
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010

Source: DFG

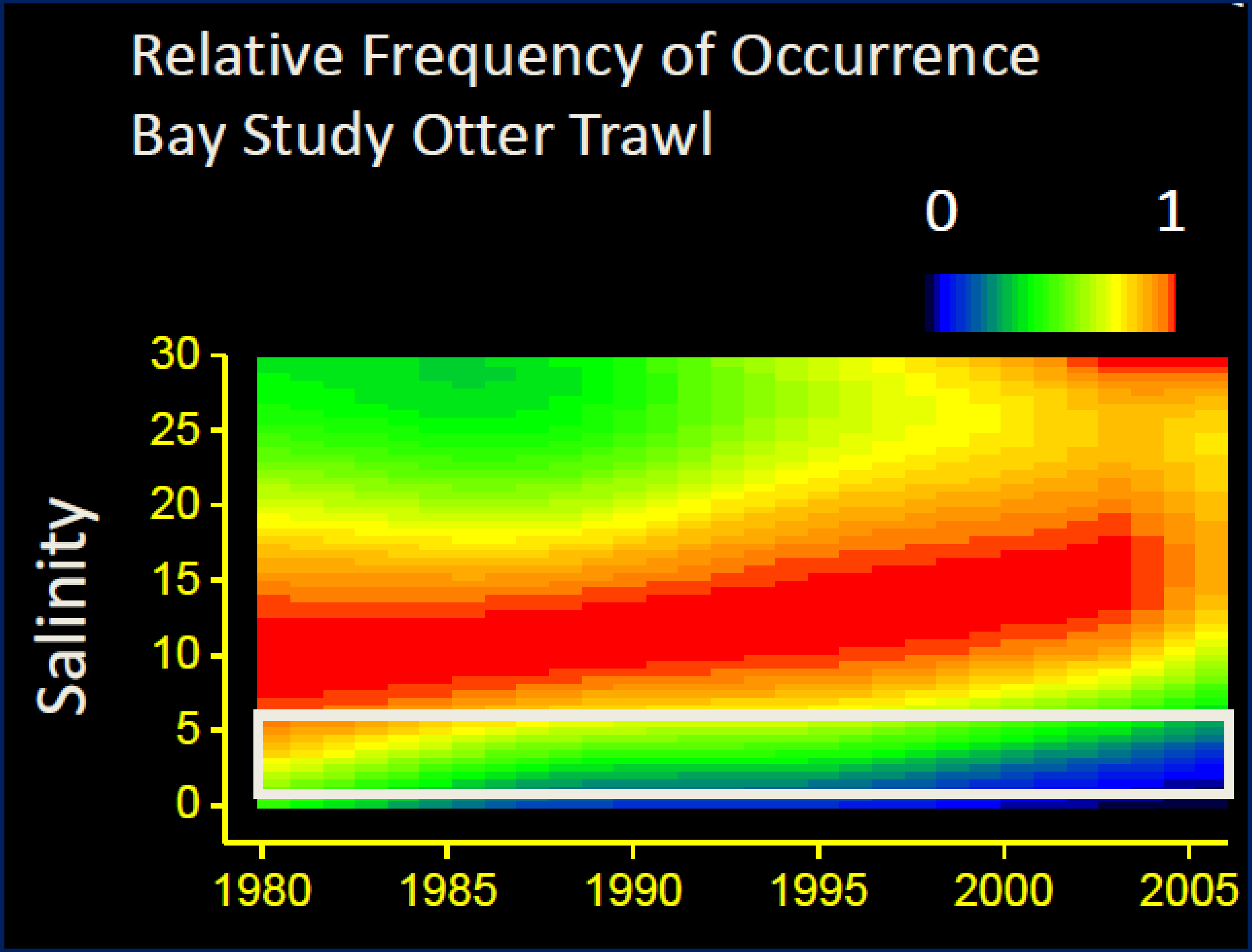


From Gray et al. (in prep).



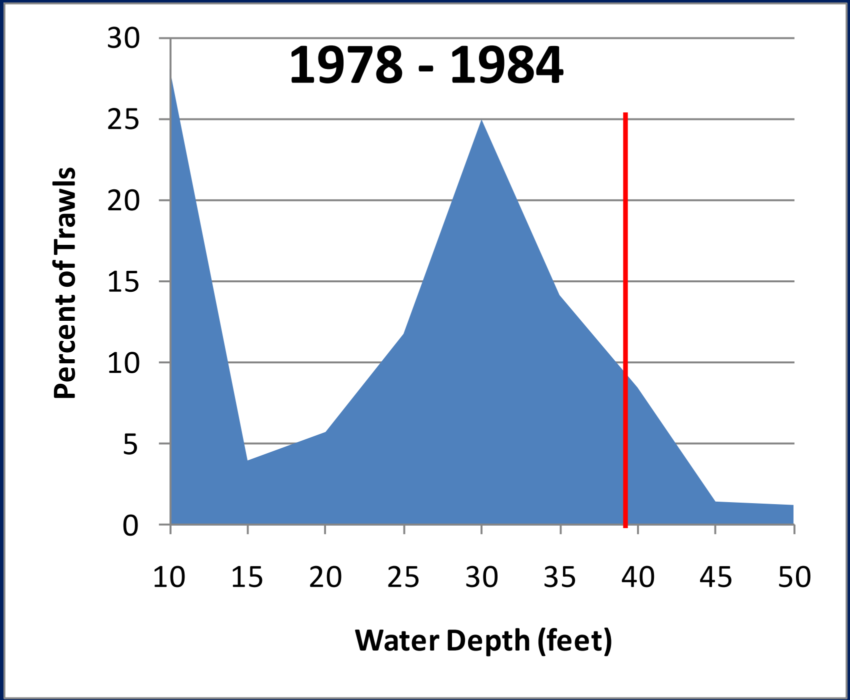
From Gray et al. (in prep).

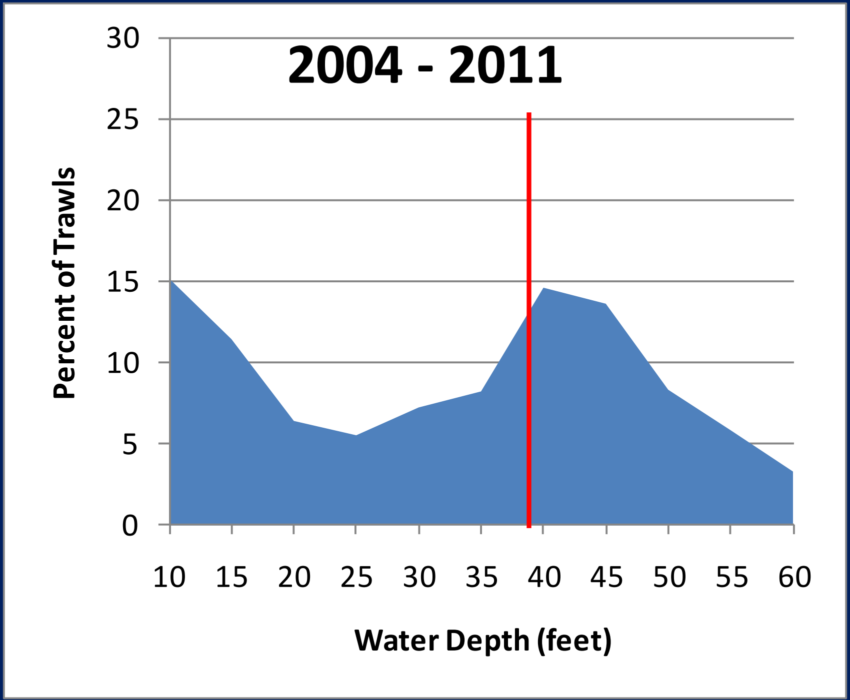
Shifts on Longfin Distribution over Time



From Kimmerer's presentation at Workshop 1, slide 20.

Water Depths Over Time in the FMWT





Source: FMWT dataset

Key Points for Longfin Smelt

- There is no demonstrated mechanism to explain the longfin FMWT: X2 correlation.

- Even if outflow *per se* increased abundance, the increases would be very small.

- Many factors other than flows are correlated with longfin smelt abundance. The most plausible causal mechanism for longfin abundance is food supply and ultimately nutrient patterns.

- Different longfin surveys show different long-term abundance trajectories.

Next up: Dr. Richard Dugdale, SFSU

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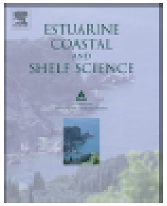

River flow and ammonium discharge determine spring phytoplankton blooms in an urbanized estuary

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ABSTRACT

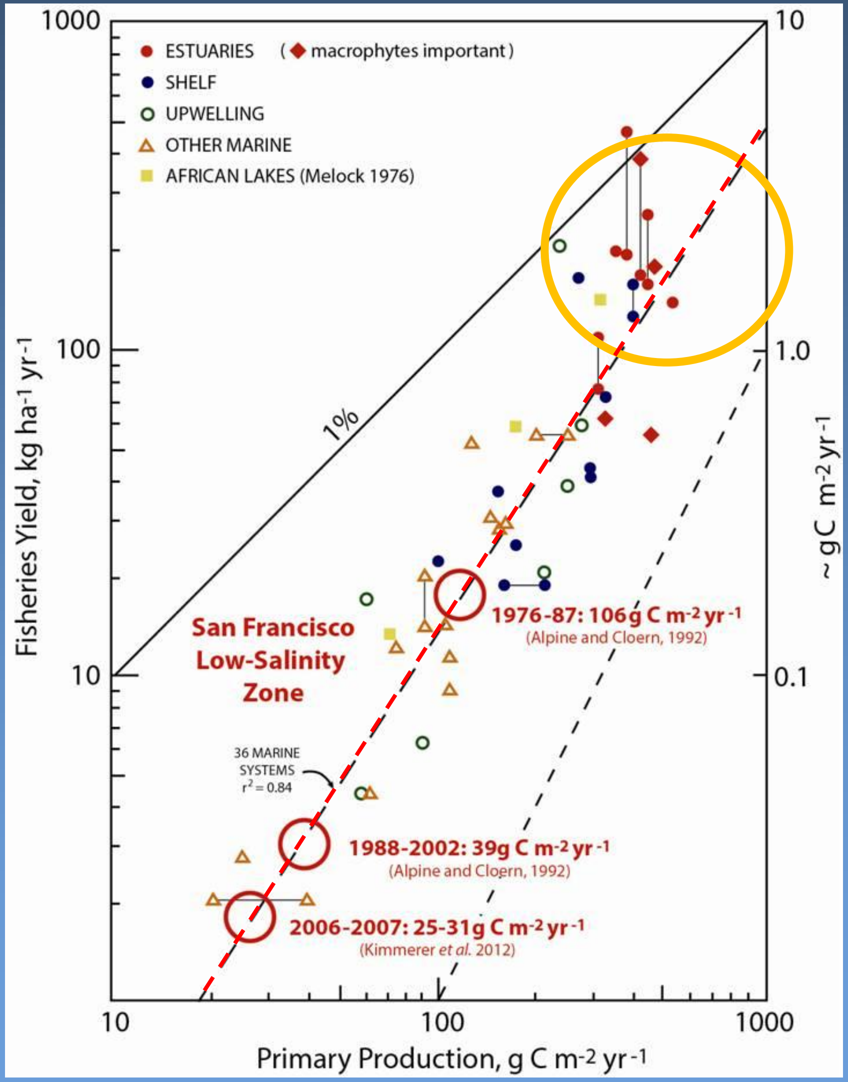
Nutrient loadings to urbanized estuaries have increased over the past decades in response to population growth and upgrading to secondary sewage treatment. Evidence from the San Francisco Estuary (SFE) indicates that increased ammonium (NH_4) loads have resulted in reduced primary production, a counter-intuitive finding; the NH_4 paradox. Phytoplankton uptake of nitrate (NO_3), the largest pool of dissolved inorganic nitrogen, is necessary for blooms to occur in SFE. The relatively small pool of ambient NH_4, by itself insufficient to support a bloom, prevents access to NO_3 and bloom development. This has contributed to the current rarity of spring phytoplankton blooms in the northern SFE (Suisun Bay), in spite of high inorganic nutrient concentrations, improved water transparency and seasonally low biomass of bivalve grazers. The lack of blooms has likely contributed to deleterious bottom-up impacts on estuarine fish. This bloom suppression may also occur in other estuaries that receive large amounts of anthropogenic NH_4. In 2010 two rare diatom blooms were observed in spring in Suisun Bay (followed by increased abundances of copepods and pelagic fish), and like the prior bloom observed in 2000, chlorophyll accumulated after NH_4 concentrations were decreased. In 2010, low NH_4 concentrations were apparently due to a combination of reduced NH_4 discharge from a wastewater treatment plant and increased river flow. To understand the interactions of river flow, NH_4 discharge and bloom initiation, a conceptual model was constructed with three criteria; 1) NH_4 loading must not exceed the capacity of the phytoplankton to assimilate the inflow of NH_4, 2) the NH_4 concentration must be $\leq 4\ \mu mol\ L^{-1}$ to enable phytoplankton NO_3 uptake, 3) the dilution rate of phytoplankton biomass set by river flow must not exceed the phytoplankton growth rate to avoid "washout". These criteria were determined for Suisun Bay; with sufficient irradiance and present day discharge of 15 tons NH_4–N d^{-1} at the upstream wastewater treatment plant. The loading criterion requires phytoplankton NH_4 uptake to exceed 1.58 mmol $m^{-2}\ d^{-1}$; the concentration criterion requires river flow >800 $m^3\ s^{-1}$ at the SRWTP for sufficient NH_4 dilution and the washout criterion requires river flow at Suisun Bay <1100 $m^3\ s^{-1}$. The model and criteria are used to suggest how a reduction in anthropogenic NH_4, either by reduced discharge or increased dilution (river flow), could be used as a management tool to restore pre-existing productivity in the SFE and similarly impacted estuaries.

Background: *The Ammonium Paradox*

Paradigm: Excess nutrient loads cause phyto-plankton blooms (production) and may result in cultural eutrophication; degraded aesthetics, low DO, HABs.

Empirical evidence: In the northern SFE and other systems, excess NH_4 may result in low phyto-plankton production; cultural oligotrophication, (decreased algal biomass and altered phytoplankton community).

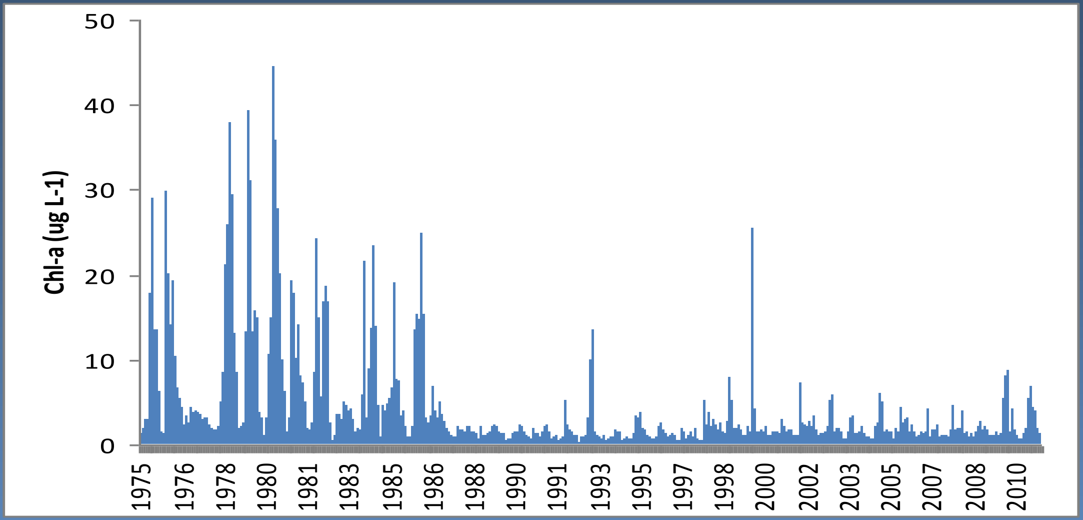
Background: *The Link Between Phytoplankton and Fish Yield*

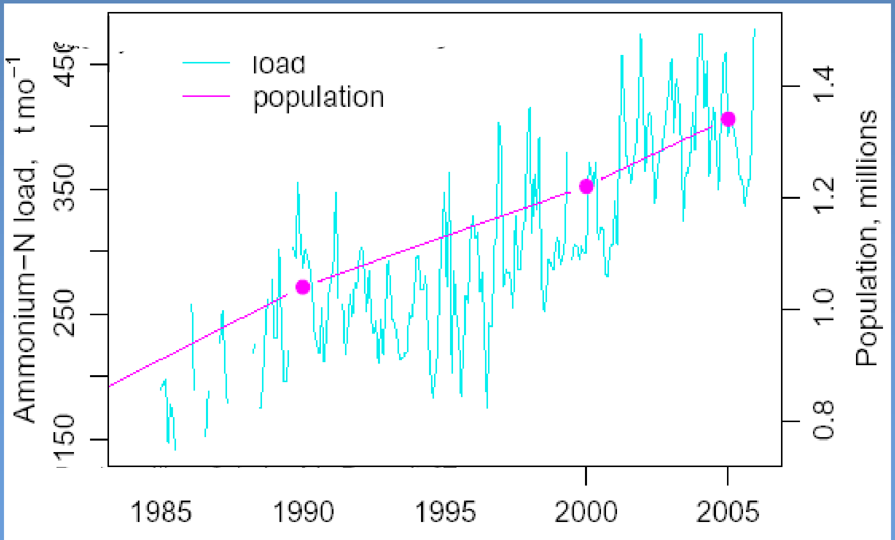


Background: *Long Term Trends in Ammonium and Phytoplankton*

Chl-a decline due to benthic grazing…

but decline predates clams.





Spring blooms in 2000 and 2010 cannot be explained by clams.

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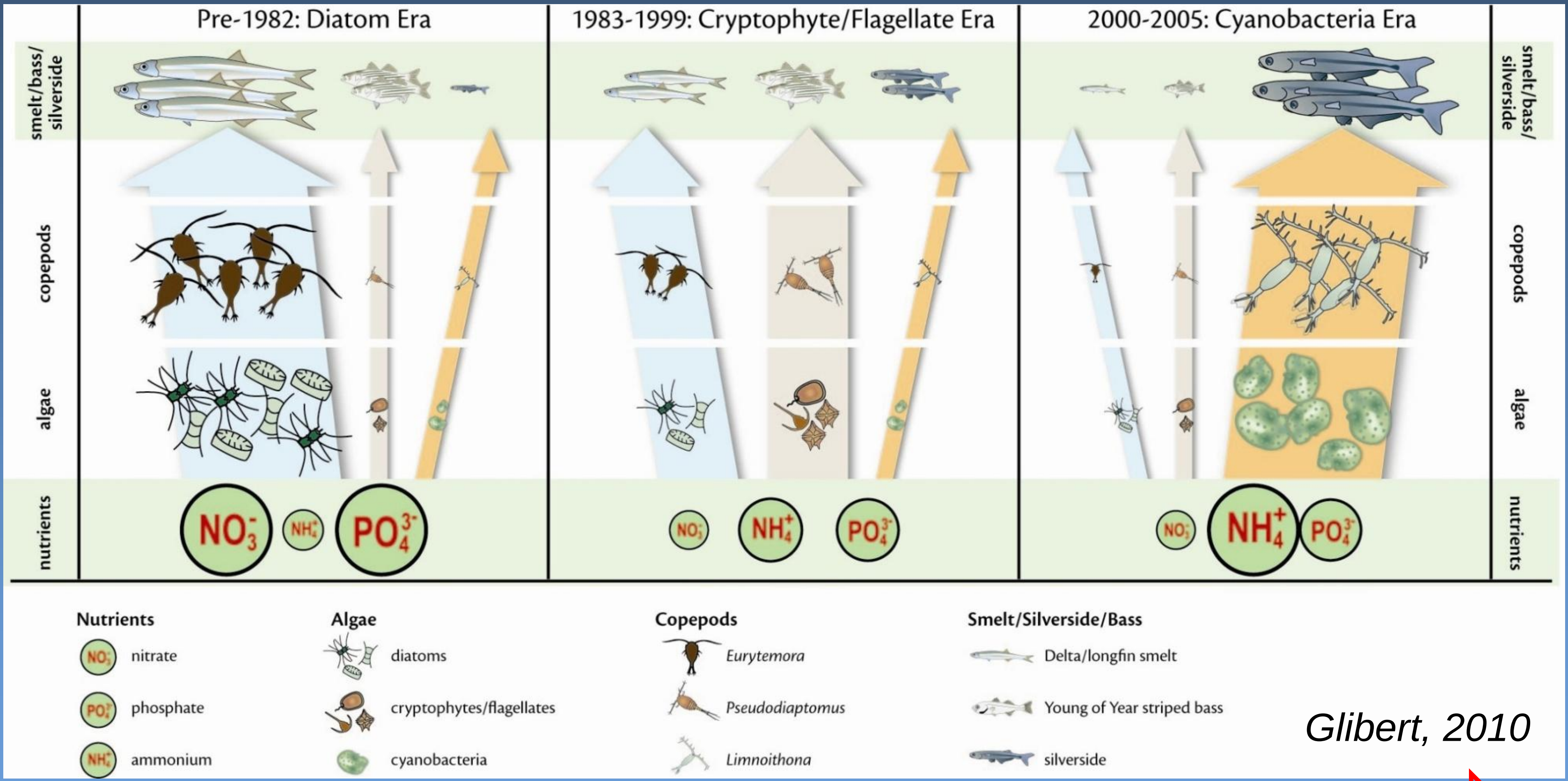
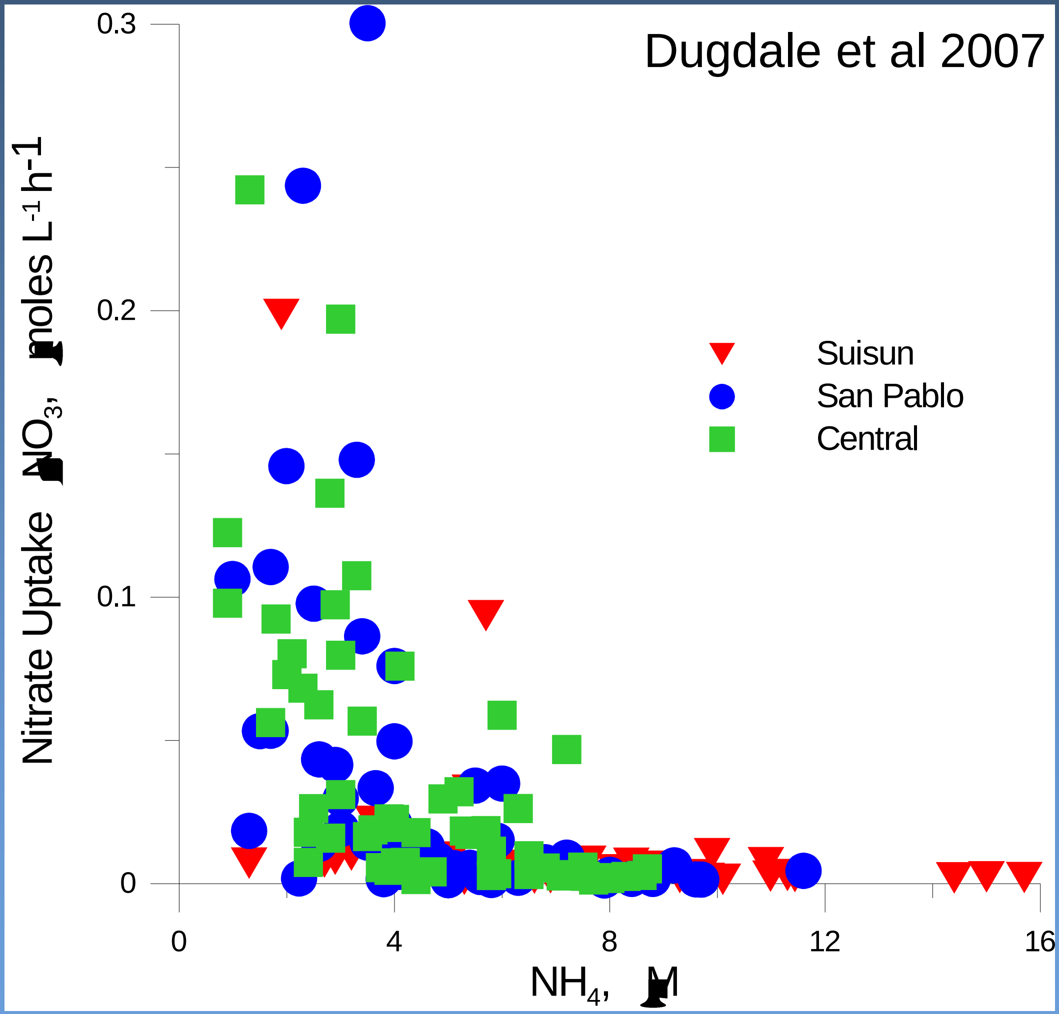
Background: *Nutrients Alter Foodwebs*



Glibert, 2010

Increasing contribution by NH_4

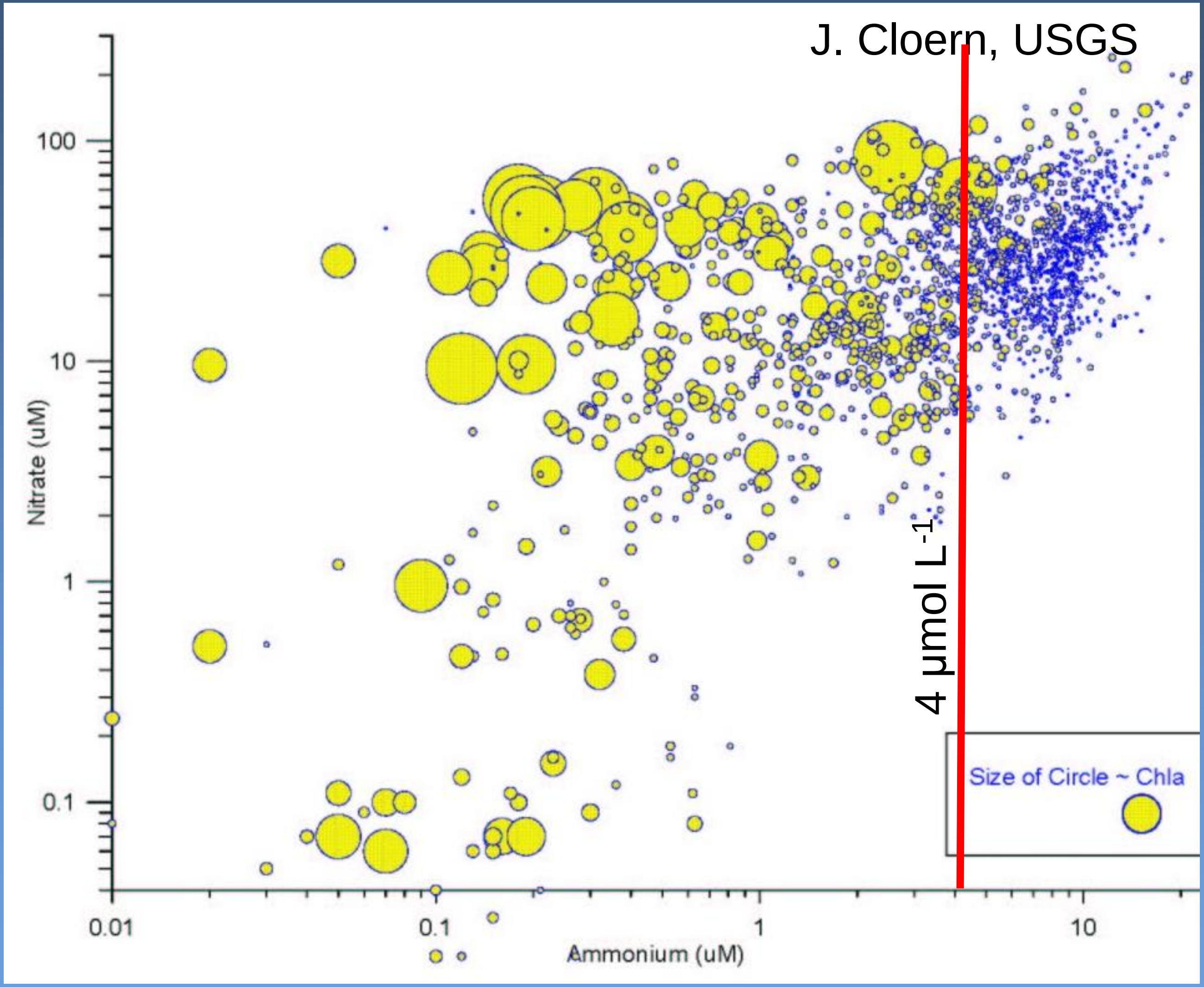
Background: *Ammonium Interferes with Phytoplankton Nitrate Physiology*



NH_4 > 4µmol L^{-1} (0.056 mg L^{-1}) virtually ELIMINATES phytoplankton NO_3 uptake

NH_4 > 1µmol L^{-1} (0.014 mg L^{-1}) substantially REDUCES phytoplankton NO_3 uptake

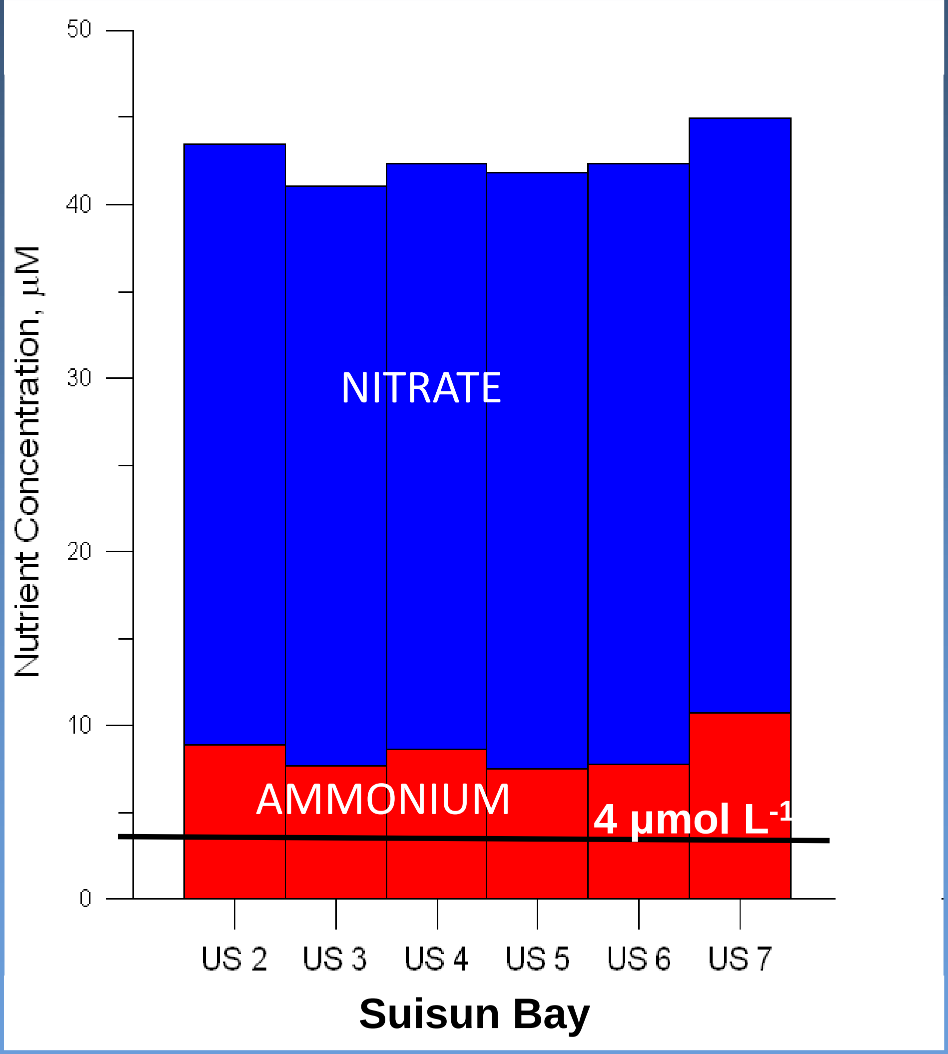
Background: Ammonium Reduces Phytoplankton Biomass



USGS monitoring shows that NH_4 >4µmol L^{-1} is not associated with chl-*a*.

Chl-*a* associated with low NH_4 and high NO_3.

Background: *Ammonium and Nitrate in the SFE*

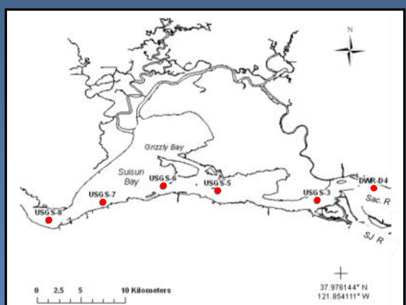


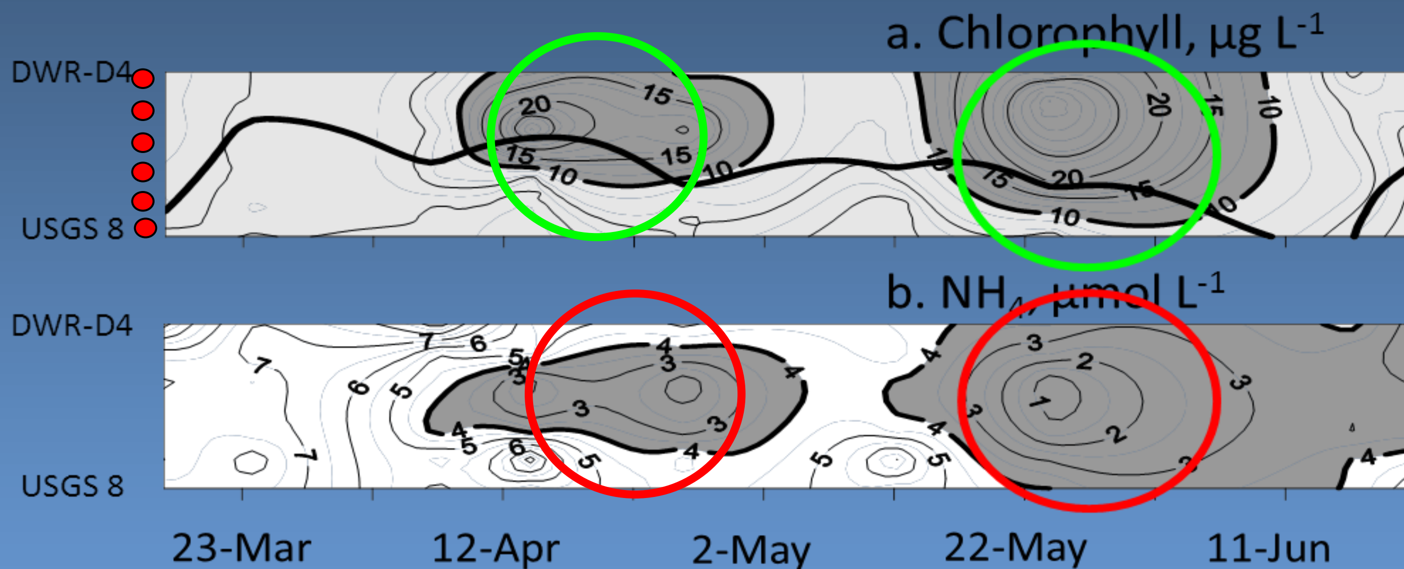
1 µmol N L^{-1} = 1µg chl-*a* L^{-1}

If phytoplankton use all N (e.g. in a culture flask) then the initial N conc. is predictive of the final chl-*a*

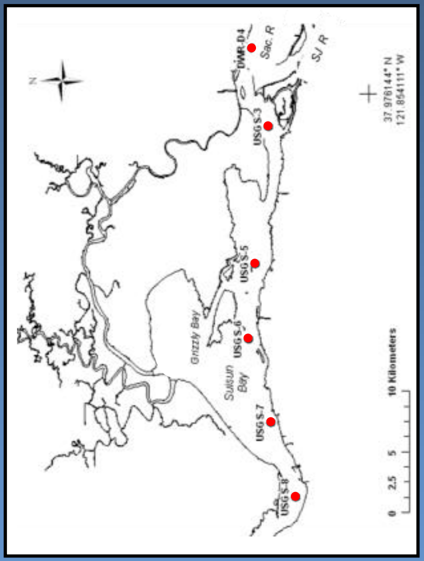
In the northern SFE NO_3 is the largest pool (ca. 75%) of nitrogen. Most N NOT used by phytoplankton

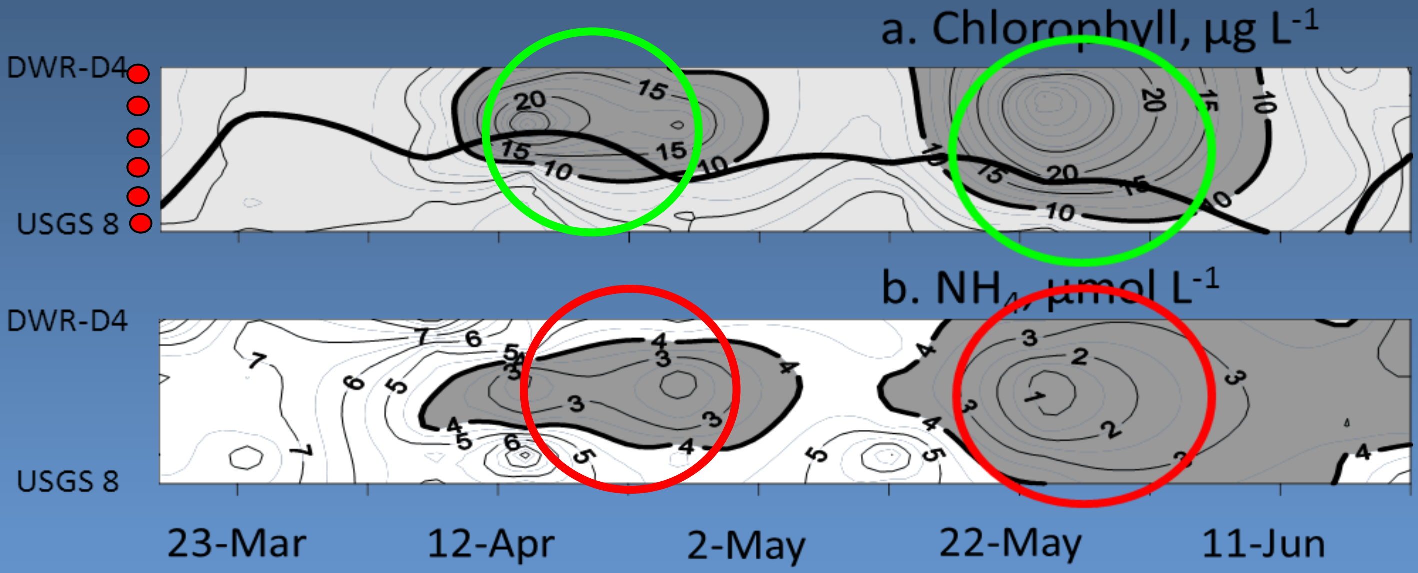
What Can Anomalous Blooms Tell Us About Controls on Phytoplankton Growth?





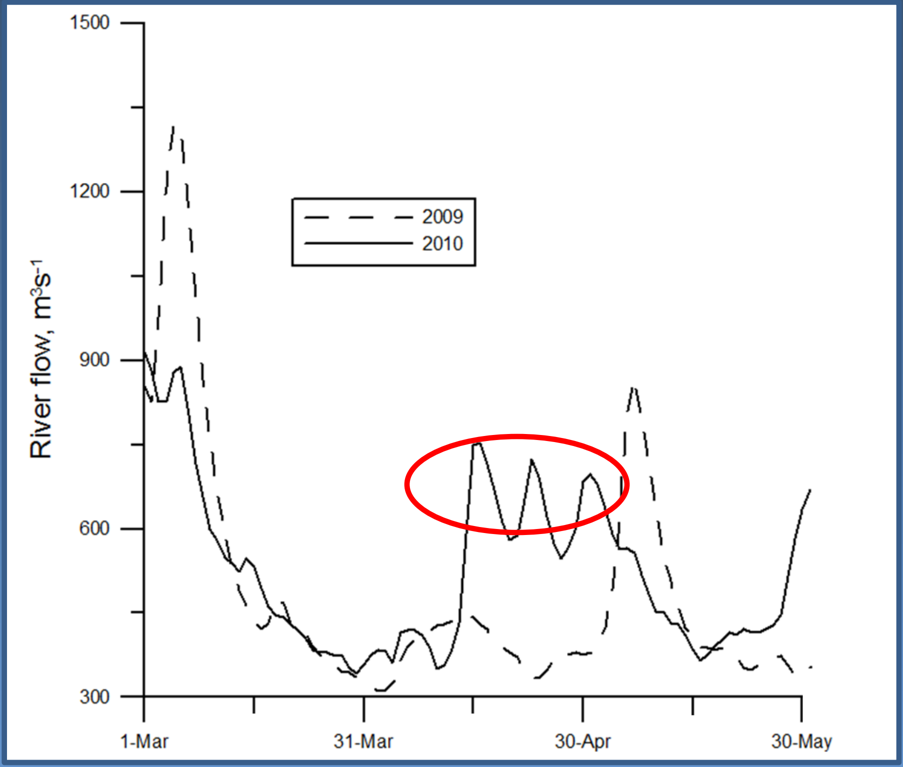
What Can Anomalous Blooms Tell Us About Controls on Phytoplankton Growth?





2010 phytoplankton bloom when $NH_4 < 4$ µmol L^{-1}

2010 vs. 2009: What Contributed to the Lower NH_4 in 2010?



April	Effluent Discharge, tons N d^{-1}
2009	15.54
2010	14.42

Conc. / Washout Criteria

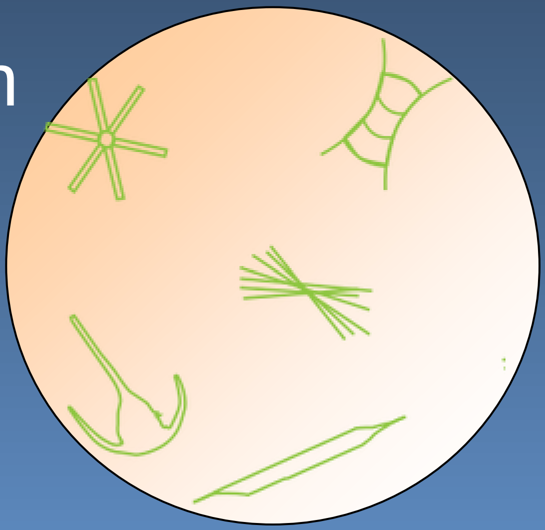
Flow rate 2010 was >50% compared to 2009

Loading Criteria

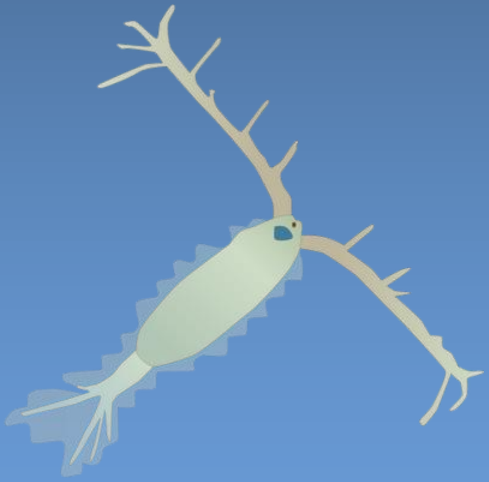
Decreased NH_4 discharge at WWTP in April 2010

Consequences of the 2010 Bloom on the Pelagic Food Web

Phytoplankton increase 10-fold.



Zooplankton increase 9-fold over 2009

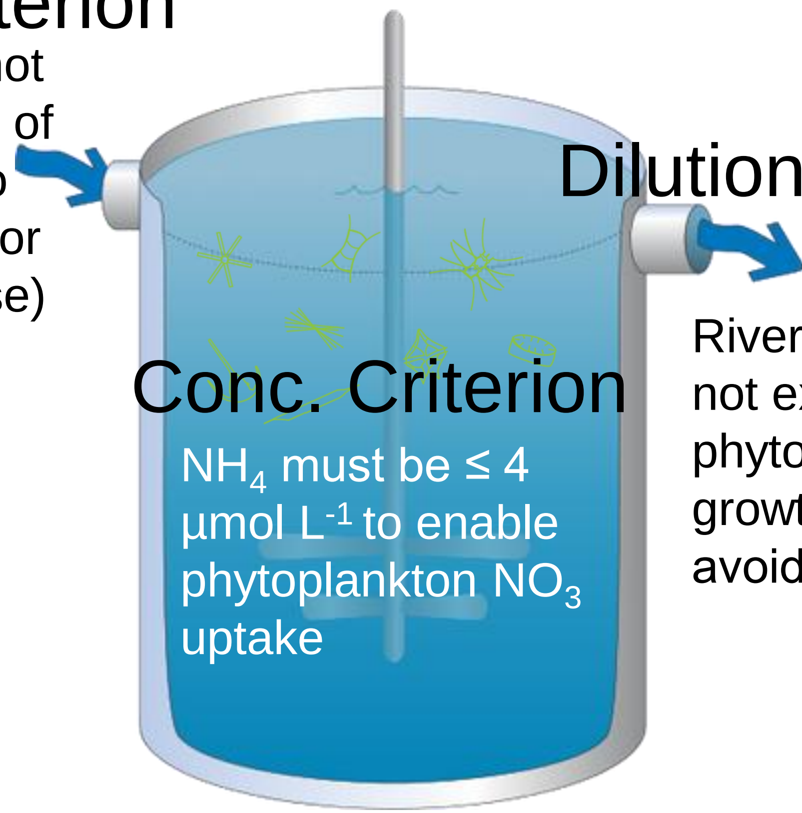


Delta smelt (70%) and longfin smelt (194%) increased (FMWT survey)

River Flow and NH_4 Discharge Control Spring Phytoplankton Blooms in the Northern SFE

Loading Criterion

NH_4 load must not exceed capacity of phytoplankton to assimilate NH_4 (or NH_4. will increase)



Dilution Criterion

River flow, must not exceed the phytoplankton growth rate to avoid “washout”.

Criteria Values for Suisun Bay with Present Day NH_4 Loading of 15 tons NH_4-N d^{-1}

1. *Loading Criterion* requires phytoplankton **NH_4 uptake > 1.58 mmol m^{-2} d^{-1} (unlikely) (Suisun uptake rates range from a mean of 0.88 to max of 2.02 mmol m^{-2} d^{-1})**

2. *Concentration Criterion* requires **river flow >825 m^3 s^{-1} (29,000 cfs)**

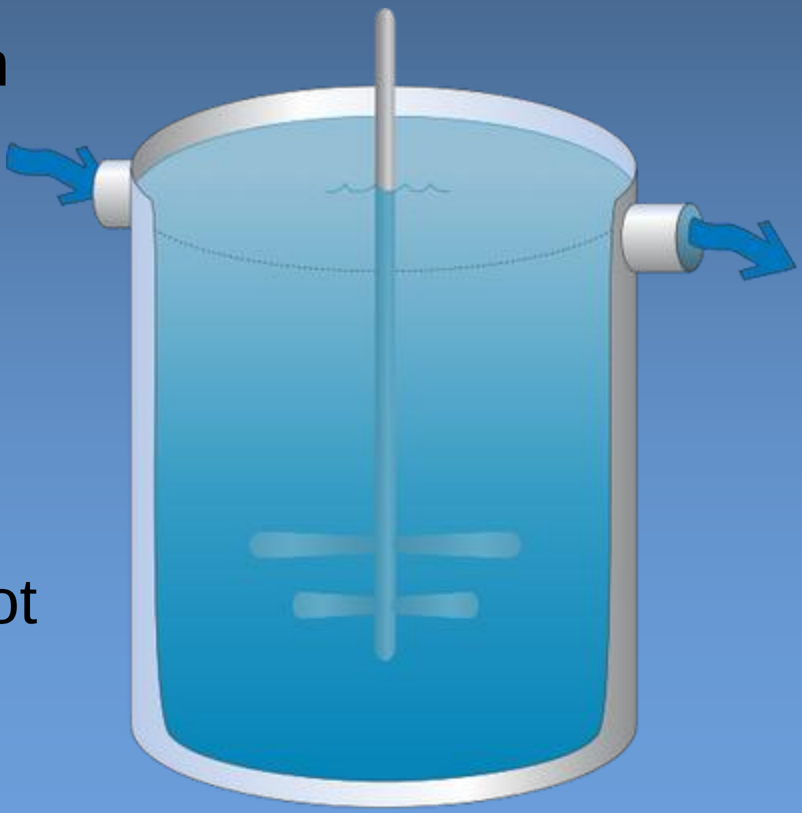
3. *Washout Criterion* requires **river flow at Suisun Bay <1100 m^3 s^{-1} (39,000 cfs)**

What Does this Mean for Managing Nutrients and Flow in the Estuary?

Based on the three criteria, the most effective management action is to ***reduce the NH_4 discharge*** **:**

- This addresses the loading criterion and the concentration criterion (which increases the flow/nutrient “window”) and both increase the probability of bloom formation.

- Increasing flow alone will improve ***Concentration Criterion*** but will not influence ***Loading Criterion and will quickly exceed the Washout Criterion***



END

Conclusions

- Salmon
- Delta smelt
- Longfin smelt