Public Workshop (9/5-6/12)
Bay-Delta Workshop 1
Deadline: 8/17/12 by 12 noon

STATE OF CALIFORNIA – CALIFORNIA NATURAL RESOURCES AGENCY

EDMUND G. BROWN JR., *Governor*

DEPARTMENT OF WATER RESOURCES
1416 NINTH STREET, P.O. BOX 942836
SACRAMENTO, CA 94236-0001
(916) 653-5791

August 17, 2012

RECEIVED
8-17-12
SWRCB Clerk

State Water Resources Control Board
1001 I Street
Sacramento, California 95814

Via email: commentletters@waterboards.ca.gov

Subject: Bay-Delta Workshop 1 - Ecosystem Changes and LSZ

Dear Chairman Hoppin and Members of the Board:

The Department of Water Resources (DWR) appreciates the opportunity to participate in the upcoming workshop process in order to present the new science that has emerged since the State Water Resources Control Board (State Water Board) released its staff report in 2009. There is a significant amount of new understanding regarding the physics, chemistry and biology of the San Francisco Bay / Sacramento-San Joaquin Delta Estuary (Bay-Delta). Through its participation in the workshops and public hearing process, DWR will present what it believes is the most current scientific understanding of the multifaceted Bay-Delta and identify the areas in which additional information is needed. The attached report is the first step in presenting that science.

Much of what DWR discusses in the report supplants the understanding expressed in the 2009 Staff Report. Principally, the historic notion that river flows and the location of the low salinity zone are the master variables to restoration of the Bay-Delta is eroding under scrutiny. Rather, it is clear that the whole range of ecosystem stressors must be considered in the context of the whole suite of target species, seasonal and annual variation, spatial variation, and a constantly changing landscape and biota. In short, the relative importance of flow is unknown.

DWR appreciates the difficult position of the State Water Board when the best available science indicates that the traditional approach is no longer appropriate. However, there are alternatives that allow for greater adaptive management. An adaptive approach will provide the State Water Board with the tools necessary to respond in a uniquely variable hydrology. Also, recognition in the Water Quality Control Plan that decisions over water allocation will necessarily require adaptive management will also address important trade-offs between beneficial uses. In some cases, it will require choices between fish species. Good examples of adaptive plans are the California Water Plan and the Bay-Delta Conservation Plan.

The State Water Board has begun this hearing process at a critical time when considerable new information is coming to light, only a fraction of which is currently analyzed and presentable. Through careful coordination with other processes and patience to await the results of ongoing and recently concluded studies, the State Water Board will have an unprecedented amount of information on the biology of the Bay-Delta. DWR urges that the update to the Water Quality Control Plan incorporate the results of the studies and processes to the utmost extent possible, including information that comes to light after the workshops.

Thank you for consideration of these comments and the attached report. If you have questions, feel free to contact me at (916) 653-8045.

Sincerely,

Katherine F Kelly for

Russell Stein
Acting Deputy Director

Attachment

SWRCB Workshop 1--Ecosystem Changes and the Low Salinity Zone

Department of Water Resources' Contribution

August 16, 2012

1. The Low Salinity Zone and the Effects of Stressors

Take Home Points:

- *There has been significant recent progress in understanding the physics, chemistry, and biology of the low salinity zone (LSZ).*
- *The key mechanisms for LSZ effects and their relative importance remain elusive. For this reason, it continues to be difficult to identify the relative importance of LSZ position (i.e. flow) management in relation to other stressors.*
- *Key adverse changes to the ecosystem include: contaminant inputs (e.g. ammonia, pesticides), long-term decreases in the sediment load (i.e. turbidity), the proliferation of invasive species including SAV and predators, harmful algal blooms, and a radical change in the food web.*
- *The evidence suggests that many of the pelagic resources of the low salinity zone have declined substantially, although responses in 2011 and early 2012 suggest that there is still some resilience.*
- *FLaSH results from 2011 and early 2012 showed improved delta smelt numbers, but the relative contribution of higher flow in fall 2011 remains inconclusive.*
- *Areas outside of the low salinity zone (e.g. North Delta complex) including Liberty Island and Cache Slough are much more important than previously understood.*
- *Many of these factors affecting the ecosystem are difficult to manage.*

Suggested near- to long-term actions:

- *Continued research to examine the mechanisms by which these factors affect aquatic species and their habitat.*
- *Implement regulations to decrease loading of key contaminants.*
- *Develop response plans for specific changes such as invasive species (see below)*
- *Continued research to examine the mechanisms by which flow may affect aquatic species.*
- *While much remains to be learned, there appears to be enough information to justify large scale restoration projects if an adaptive management approach is used.*

Summary of New Information:

One of the challenges in describing the low salinity zone (LSZ) is that it requires an understanding of not only the physical, chemical, and biological factors that influence the region, but also how these factors change inland to seaward. For the purposes of this discussion, we have chosen to organize the new information about the LSZ and regional stressors based on the basic Pelagic Organism Decline (POD) model (Sommer et al. 2007; Baxter et al. 2010). The specific areas covered in this summary include: 1) fish abundance; 2) habitat; 3) top-down effects (predation, entrainment); and 4) bottom up (food) effects. For each we describe some of the new information gathered since 2009 and provide information about the degree to which each may be linked to the LSZ. Much of the background information for each of these topics is available in Baxter et al. (2010).

1.1 Fish Abundance and Distribution

The decline of the pelagic fishes of the upper San Francisco estuary has been well-documented (Sommer et al. 2007; Baxter et al. 2010; Thomson et al. 2010). As noted in Baxter et al (2010), one of the concerns is that chronically low abundance of species like delta smelt may create a negative feedback loop (i.e. Allee effects), that can lead to a “downward spiral” in the population. In other words, populations lose resiliency and therefore cannot respond to favorable conditions. New research related to the distribution and abundance of pelagic fishes of the LSZ includes the following:

1.1.1 Reponses of delta smelt in 2011 and early 2012 suggest that the species maintains some resilience

One of the initial findings of the 2011 FLaSH studies was that delta smelt abundance increased substantially in 2011. Moreover, the initial results from the 2012 DFG 20 mm survey suggest that improved adult numbers in fall 2011 may have contributed to one of the best juvenile spring indices of the past decade. The subsequent 2012 Summer Townet Index was not as high as 2011, but is at least higher than all other indices since 2004. This indicates that the species still maintains some ability to respond to favorable conditions.

Level of certainty of this information: HIGH.

Relevance to the LSZ: The improved abundance of delta smelt in 2011 was remarkable, but the relative role of flow remains unclear. Multiple factors may have benefited delta smelt including flow, moderate temperatures, high turbidity, and improved food supply.

1.1.2 Part of the declines can be explained by shifts in fish distribution

Current abundance trends rely on long-term surveys in geographically fixed locations. However, there is new evidence that catch in these surveys is affected by shifts in distribution away from the core channels where sampling occurs. For example, Baxter et al. (2010) show that longfin smelt have shifted their abundance seaward. Historically, large numbers of longfin smelt remained in Suisun Bay in the LSZ through summer. In recent years there is strong evidence that the species has shifted to more saline and deeper habitat. Moreover, recent otolith work by Hobbs et al. (2010) indicates the survival of young smelt can be affected by their distribution along the axis of the estuary. It is possible that delta smelt may have exhibited the opposite distributional response to longfin smelt. As described in Sommer et al. (2011a) and Sommer and Mejia (In review), large numbers of delta smelt occur in the Cache Slough Complex and the Deep Water Ship Channel, well upstream of the LSZ. Unfortunately, there are insufficient long-term data from these channels to determine whether use of these freshwater habitats has increased in recent years. In addition to the longitudinal shifts described for the two smelts, there is good evidence that at least one of the pelagic fishes has undergone a lateral shift in distribution. Sommer et al. (2011b) found that the longitudinal distribution of young striped bass has not changed in relation to the LSZ; however, there has been a lateral shift towards inshore habitat.

Level of certainty of this information: MODERATE.

Relevance to the LSZ: These studies indicate that the current long term trawls in the channels and shoals of the LSZ underestimate the distribution and abundance of the smelts and juvenile striped bass. This does not mean, however, that the distribution shifts fully explains the POD. The declines in these fishes are too extreme to be fully explained by the apparent moderate distribution shifts. In addition, the evidence that these fishes are increasingly rare in some of the main channels of the LSZ is cause for concern. It is unclear if the distribution shifts are a result of active behavioral choices, or an apparent change caused by higher mortality in the LSZ channels. Regardless, a current hypothesis is that LSZ channels have become less suitable as a result of a decline in food supply (Sommer et al. 2011b).

1.1.3 Importance of the Cache Slough Complex for delta smelt

A key recent finding is that delta smelt heavily use the Cache Slough Complex, a region located far outside the LSZ (Sommer et al. 2011a; Sommer and Mejia, In review). At least some delta smelt occur year-round in the region. Although it is unclear what percentage of the population occurs in this region, survey data suggests that this area can seasonally support the majority of the delta smelt catch. These findings were relatively unexpected as there had previously been a general assumption that delta smelt leave the north Delta after larval stage (Sommer et al. 2011a). Moreover, flooded islands were generally considered poor-quality habitat for delta smelt in other parts of the Delta (e.g. Grimaldo et al. 2004; Nobriga et al. 2005), yet results from the USFWS beach seine and larval fish surveys show consistent use of Liberty Island and Sacramento Deep Water Ship Channel, two major features of the Cache Slough Complex (Sommer eta 2011a; Sommer and Mejia, In review).

Level of certainty of this information: HIGH

Relevance to the LSZ: These results suggest that management of delta smelt should consider not just the LSZ, but also outside areas.

1.2 Habitat

Defining the “habitat” of pelagic fishes in the estuary presents special challenges since it represents a combination of fixed geographical features as well as the water that moves across the landscape in response to tides and inflow. For the purposes of this report, we focus on some of the new evidence about physical, chemical, and biological conditions that support pelagic fishes such as delta smelt. We emphasize that this does not mean that this report assumes that habitat is the primary driver of pelagic fish populations. To the contrary, there is substantial evidence that delta smelt are controlled by a complex set of multiple interacting factors (Sommer et al. 2007; Baxter et al. 2010; MacNally et al. 2010; Sommer and Mejia, In review). Nonetheless, it is clear that aquatic habitats in the Delta have changed substantially since the mid-1850s by increasing urbanization, dam and levee construction, wetland diking and draining, water diversions, and contaminant inputs (Atwater 1985; Baxter et al. 2010). Highlights of new research in this area include the points summarized below.

1.2.1 Continued evidence that the distribution of delta smelt and other species are affected by location of LSZ

It is well-understood that higher flow levels shift the LSZ downstream, as commonly represented by X2, the distance of the 2 psu salinity isohaline from the Golden Gate Bridge (Jassby et al. 1995; Kimmerer 2002). However, there have been upstream shifts in the LSZ during fall (Feyrer et al. 2007), when the issue has become most controversial. As expected in an estuary, the distributions of many organisms are affected by the position of the LSZ (Jassby et al. 1995; Dege and Brown 2004; Feyrer et al. 2007).

Studies since 2009 continue to show that salinity is an important driver of fish distribution. Kimmerer et al. (2009), Feyrer et al. (2010), and Sommer and Mejia (In review) have used Generalized Additive Modeling (GAM) to demonstrate that the distributions of many fishes of the estuary are strongly associated with salinity. This finding is consistent with Sommer et al. (2011a), who found that the center of distribution of delta smelt is strongly associated with the LSZ as indexed by X2 (although there is an understanding that many of the fish occur outside of the LSZ at locations such as Cache Slough Complex). Similarly, Sommer et al. (2011b) showed that the center of distribution for juvenile striped bass is largely driven by the position of the LSZ as indexed by X2. The effects are not limited to fishes as there is evidence from Peterson and Vayssieres (2010) that annual patterns in benthic communities are driven, in part, by salinity. Note, however, that there are no long-term trends in the salinity of the upper estuary for many months of the year (Jassby et al. 1995; Enright and Culberson 2010).

> *Level of certainty of this information:* HIGH.
>
> *Relevance to the LSZ:* These findings support the idea that the LSZ is a biologically important area in the estuary for several fishes, even though their habitat is not restricted to the LSZ (e.g. see 1.1.3). While the effects of LSZ on abundance are unclear for some species and seasons, the association between the center of distribution of estuarine organisms and LSZ position is reasonably well-understood.

1*.2.2. The results of Fall Low Salinity Habitat studies (FLaSH) remain inconclusive*

One of the most ambitious new research efforts is the Fall Low Salinity Habitat (FLaSH) program. FLaSH is a multi-agency study in response to the 2008 OCAP Delta Smelt Biological Opinion's (BO) Reasonable and Prudent Alternative that called for "adaptive management" of fall flows in wetter water years (USFWS 2008). The basic hypothesis of the RPA is that the LSZ (salinity 1-6 ppt) may have greater benefits when its geographic location is further downstream (seaward) during fall. A suite of studies were initiated by Interagency Ecological Program (IEP) in 2011 to examine the response of the upper estuary to increased flows during fall of that year (USBR 2012). A draft report summarizing the results of the 2011 studies has been prepared and is currently undergoing peer review, so it is currently not available or citable. Nonetheless, some of the basic results have been discussed at the recent 2012 IEP Annual Workshop. Highlights of the talks included the following:

- IEP was able to mobilize a major study program to take advantage of higher fall flows in 2011.
- The results of the 2011 studies remain <u>inconclusive</u> for several reasons:
    - The primary results are from just a single year (statistically this means "n = 1").
    - Many of the 2011 investigations have not yet been completed.

    - This report hasn’t yet been peer-reviewed.
    - It is difficult to separate what was observed in fall 2011 from the relatively good conditions throughout the rest of the year (e.g. high flow, low temperature, new spring OMR flow regulation).
    - Some of the results contradicted initial predictions of the study.
- In addition to relatively high numbers of delta smelt in fall 2011, growth rates (both apparent and based on otoliths) were also high compared to previous years.
- There was a rare fall phytoplankton bloom that occurred near Rio Vista (upstream of the FLaSH prediction for a bloom in the LSZ). Initial studies showed that the bloom was composed mostly of diatoms, and that an important source of productivity for the bloom may have been Cache Slough Complex.
- High flow conditions in 2011 led to a reduction in spring *Potamocorbula* biomass and grazing rates.

Level of certainty for this information: LOW.

Relevance to the LSZ: These studies are highly relevant since the target region is the LSZ. Additional information should be available later in the year. However, the fact that the study was conducted in just a single year means that no definitive answers will be available for some time. A suite of studies over the next several years should help to progressively reduce uncertainty.

1.2 3 It continues to be difficult to separate the relative importance of the LSZ position from the effects of multiple interacting factors

Because of the complexity of the San Francisco estuary and the suite of potential management tools, it would be helpful to be able to identify the relative importance of different stressors that affect the biota of the LSZ. Conceptual models at least provide an accounting of the major categories of stressors and suggest ways in which they interact. Some of the available tools include the previously-described basic conceptual model for the POD (Sommer et al. 2007), species models for delta smelt, longfin smelt, striped bass, and threadfin shad (Baxter et al. 2010), a regime shift model (Baxter et al. 2010), and an adaptive management model for how biota may respond to changing management of the LSZ during fall (BOR 2011). The existence of these models does not, however, mean that they are necessarily accurate. Indeed, all of these models were developed to generate testable hypotheses for research and management.

Even with good conceptual models, it is challenging to identify the key stressors for a given species, time period, and location. Nonetheless, scientists and managers are fortunate to have multi-decade IEP databases that can at least be used for exploratory data analyses. Two such efforts were recently completed by IEP using a team of local and outside scientists organized through the National Center for Ecological Synthesis and Analysis (Thomson et al. 2010; Mac Nally et al. 2010). Some of the highlights of the two studies included the following:

Thomson et al. (2010) – Bayesian change point analysis

- Turbidity and winter exports were important factors associated with annual fall abundance of delta smelt
- For longfin smelt, the long-term population trend was associated with turbidity and spring X2.
- Age-0 striped bass was associated with turbidity and an autocorrelation with abundance in previous years.
- There was weak evidence for winter and spring exports and calanoid copepod abundance being important for long-term trends in threadfin shad.
- For all four species, these factors analyzed could not account for the POD decline beginning around 2000.

Mac Nally et al. (2010) – Multiple autoregressive analysis (MAR).

- MAR modeling confirmed that 28 of 54 proposed relationships between the four POD fishes and abiotic and biological factors play a role in driving fish abundance trends.
- High values of spring X2 (i.e. lower flows) were negatively associated with abundances of longfin smelt, as well as the biomass of calanoid copepods and mysids.
- Food web factors were somewhat important.
- Some evidence for export effects on delta smelt (negative effects of high winter exports) and threadfin shad (negative effects of high spring exports).

In addition, the National Research Council (2012a) was recently given the task of examining the relative importance of different stressors and their potential for management actions. The panel's high-profile findings were very clear that excessive focus on single stressors was not fruitful. Key findings include:

- "The large number of stressors, their effects and interactions lead to the conclusion that efforts to eliminate any one stressor are unlikely to reverse declines in listed species."
- "Opportunities exist to mitigate or reverse the effects of many stressors."
- "Continued effects analyses, modeling, and monitoring are necessary to ensure actions taken to rehabilitate the ecosystem are cost-effective."

Level of certainty of this Information:
HIGH that a focus on a single stressor will not reverse species declines.

MODERATE-HIGH that opportunities exist to improve conditions for fishes.

Relevance to the LSZ: Management of resources is most effective when the relative "bang for buck" for prospective actions is understood. However, it is clear that there are multiple interacting stressors, the effects of which cannot be readily separated. This is understandable given that the whole range of stressors must be considered in the context of the whole suite of target species, seasonal and annual variation, spatial variation, and a constantly changing landscape and biota. Indeed, the recent review by the National Research Council (NRC 2012a) indicated that it was not feasible to separate the relative importance of stressors. For this reason, it continues to be difficult to identify the relative importance of LSZ position (i.e. flow) management in relation to other stressors.

1.2.4 More information is available about the habitat needs of delta smelt

In addition to specific studies (described above and below), three new synthesis and review documents continue to build the knowledge base for some of the habitat requirements of delta smelt. These include a recent draft Delta Smelt Habitat White Paper (Sommer and Mejia, In review), the 2010 POD Work Plan (Baxter et al. 2010), and the BDCP effects analysis (BDCP 2012a). Much of the relevant information in Baxter et al. (2010) is contained in a special section about habitat. For the BDCP effects analysis, the most relevant sections are found in Appendix C, Flow, Passage, and Salinity:

- The first part of the document contains an Executive Summary along with summary tables broken out by river (reach), Yolo bypass, and the Delta showing a comparison of the proposed project to existing biological conditions (EBC) under two estimates of climate change: early long term (ELT) and late long term (LLT).
- Delta Smelt Fall Abiotic Habitat Index discussion (Section C.4.4.7) starts on C.4-67 with related discussion (including adjusted estimates to incorporate proposed restoration) to C.4-73.
- Conclusions (Section C.6) summarizes regional flow changes.
- Delta outflow (Section C.6.1.2.12) starts on p. C.6-5 with subsequent salinity, turbidity, temperature and dissolved oxygen sections.

Some of the key findings from the three documents include the following:

- Key factors for delta smelt habitat include high turbidities (>12 ntu) and moderate temperatures (7-25^{o}C).
- Delta smelt do not appear to have strong substrate preferences, but sandy shoals may be important for spawning.

- The evidence to date suggests that delta smelt generally require at least moderately tidal habitats.
- Delta smelt also occur in a wide range of channel sizes, although they seem to be rarer in small channels (<15 m wide).
- Some evidence that open water habitat adjacent to long residence time areas (e.g. tidal marsh, shoal, low order channels) may be favorable.
- Other desirable features of delta smelt habitat include high calanoid copepod densities, and low levels of submerged aquatic vegetation and the toxic algae *Microcystis*.
- Key adverse changes to the ecosystem include: contaminants, long-term decreases in turbidity, the proliferation of invasive species including SAV and predators, harmful algal blooms, and a radical change in the food web.

Level of certainty for this information: MODERATE.

Relevance to the LSZ: These reviews summarize the best available information about the habitat requirements of delta smelt, whose core distribution occupies the LSZ. They also include new information that management of delta smelt should include regions outside the LSZ such as Cache Slough Complex.

1.2.5 There have been important long-term and recent changes to physical habitat in the estuary

The San Francisco Estuary has been an area of importance to humans for centuries. Beginning in the California Gold Rush in the mid-1800s and subsequent rapid population growth, exploitation of resources accelerated rapidly (Baxter et al. 2010). Some of the most important changes include wetlands diking and draining, levee and dam construction, urbanization, water diversions, and extensive species introductions (Nichols et al. 1986). Many of these changes have been well-documented in previous reports and publications, so they will not be discussed in detail here.

One new study of interest is Brown and Bauer (2009), which describes some of the long-term changes in hydrology in relation to the life history of several of the major fishes. While the long-term decline in sediment load to the estuary is well-documented (Wright and Schoellhamer 2004), recent research suggests that there was a sudden clearing (i.e. reduction in turbidity) of the estuary around 1999 (Schoellhamer 2011).

Level of certainty of this information: HIGH.

Relevance to the LSZ: The historical loss of habitat and alterations of the estuary remain an ongoing issue for the LSZ. Suisun Bay continues to be one of the most turbid regions of the estuary because of strongly interacting tidal and riverine flows, bathymetric complexity, and high wind speeds, which resuspend erodible sediments in the region's large and open shallow bays. However, the long-term decline in sediments and apparent acceleration of clearing is of grave concern because most of the POD fishes prefer turbid water.

1.2.6 The proliferation of SAV has degraded habitat for pelagic fishes

Historically, tidal wetlands were an important habitat for native fishes in the Delta, as they provided productive and physically complex areas that served as nurseries for juveniles (Brown 2003). While land reclamation was a primary cause of the loss of this habitat, remaining wetlands of the Delta today are threatened by non-native species. In recent decades, shallow-water areas in the Delta have seen the proliferation of Brazilian waterweed (*Egeria densa*), and other non-native aquatic plants (Brown and Michniuk 2007). The influx of vegetation has made the areas largely unsuitable for native fish species that prefer open-water habitat, such as delta smelt (Brown 2003). Furthermore, dense aquatic vegetation has brought increased densities of non-native predators, such as largemouth bass (Brown and Michniuk 2007). However, the extent to which vegetation-associated predators have an impact on the populations of pelagic fishes is not clear.

Recent work has increased our understanding of how *Egeria* and other non-natives work to dominate the shallow-water community. Peak growth during fall months allows *Egeria* to persist through the winter and have higher biomass than other aquatic plants the following spring (Santos et al. 2011). In addition, *Egeria* and other non-native aquatic plants have morphological and physiological traits that give them a competitive advantage over native species (Santos et al. 2012). Dense stands of *Egeria* may act to decrease exchange between shallow water, shoreline habitats and pelagic areas. Indeed, recent evidence suggests that food webs in these habitats are largely segregated (Grimaldo et al. 2009a).

Egeria densa may have also affected the broader ecosystem by limiting sediment resuspension and thus contributing to increased water clarity in the Delta, which degrades habitat for pelagic fishes that rely on turbidity for efficient feeding and predator avoidance. Even after statistically controlling for reduced sediment input into the system, there is still a negative and significant relationship between turbidity and submerged plant cover (Hestir 2010). Annual maximum water velocities in excess of 0.49 m/s appear to help limit the establishment of submerged vegetation (Hestir 2010).

The Department of Boating and Waterways initiated an *Egeria densa* control program in 2001, using herbicides. The program has been moderately successful in Frank's Tract, and other areas that typically experience heavy boat traffic (DBW 2009); however, we don't know if the reduction in *Egeria* by this program reduces coverage to the extent that it can limit the effects that the plant has on the overall Delta ecosystem.

> *Level of certainty for this information:* MODERATE
>
> *Relevance to the LSZ:* When the LSZ overlaps with the distribution of *Egeria densa* (prevalent as far west as Sherman Island), shallow-water habitat for open-water species, such as delta smelt, will be extremely limited. While it is understood that lower flow conditions results in an upstream shift of the center of distribution of LSZ fishes, the relative effects on predation risk from non-native predators such as largemouth bass is unknown.

1.2.7 Increasing evidence that ammonia inputs are a concern for the food web

The effects of increased ammonia concentrations on the Sacramento-San Joaquin Delta and Suisun Bay have been the point of considerable research and regulatory review. Ammonia loading has been increasing substantially (Jassby 2008) over the last several decades. Coincidentally, primary production and standing chlorophyll *a* levels associated with phytoplankton are among the lowest of all the major estuaries in the world (Jassby et al. 2002; Cloern and Jassby 2008; Jassby 2008).

The downward trend in the abundance and productivity of algae over the last several decades has been coupled with the general shift in the phytoplankton community composition from diatoms toward less desirable cyanobacteria (“blue-green algae”) and flagellates (Lehman 1998, 2000a,b; Jassby 2008; Brown 2010) as predicted for an ammonia rich system (Dugdale et al. 2007). Diatoms are assumed to be more nutritious to primary consumers like zooplankton than flagellates and blue-green algae and this reduction in algal food availability or its quality is a “bottom up” effect, one of the four factors hypothesized to contribute to the POD (Sommer *et al*. 2007; Baxter et al. 2010).

Studies over the past two decades provide evidence that ammonium-induced suppression of nitrate uptake prevents spring diatom blooms from developing when conditions are otherwise favorable. It has been observed that spring diatom blooms only occur in years when ambient ammonium is below levels reported to inhibit nitrate uptake and algal production. Focused monitoring in spring 2010 detected two diatom blooms in Suisun Bay (Foe et al. 2010). Both occurred when ammonium was below the nitrate uptake “shutdown” level (0.056 mg/L). At times when ammonium levels in Suisun Bay were above this threshold, no blooms were observed.

There are also concerns that current ammonium levels may suppress diatom growth along the axis of the estuary (Wilkerson et al. 2006) including the Delta upstream from Suisun Bay.

Results from two recent studies (Parker et al. 2010 a,b) indicate that ammonium levels in the river downstream of the Sacramento Regional Water Treatment Plant (SRWTP) were high enough to suppress nitrate uptake in algae. Additionally, primary production and chlorophyll levels peaked above the SRWTP and again in San Pablo Bay, consistent with the earlier observations near the LSZ that ammonia concentrations suppress algal primary production (Foe et al. 2010).

Glibert (2010) has examined whether nutrient loading changes and food web responses were linked. The study found that there was a measureable change in the ratio of nitrogen to phosphorous (the N:P ratio) in the Delta, an increase in total N loading, a decrease in total P loading, and a change in the dominant form of nitrogen from nitrate to total ammonia. Glibert (2010) observed that changes in nutrient concentrations were correlated with changes observed in the Delta's food web and that these changes may be related to the POD. Not only was the increase in ammonium loads from wastewater discharge in the upper Sacramento River common to all of these loads and ratios, but so was the timing of these changes.

Although there is no direct evidence of ammonia effects on higher trophic levels, food limitation has been a frequent concern in the estuary. Slaughter and Kimmerer (2010) observed lower reproductive rates and lower growth rates of the copepod, *Acartia* sp., in the LSZ compared to taxa in other areas of the estuary. They conclude that "the combination of low primary production and the long and inefficient food web have likely contributed to the declines of pelagic fish." Other recent evidence suggests that delta smelt are food-limited based on analyses of their liver glycogen levels (Bennett et al. 2008). Additionally, evidence exists of food limitation in longfin smelt (Rosenfield and Baxter 2007; CDFG 2009).

Regarding toxicity to fish, un-ionized ammonia levels in the Delta appear to be too low to cause acute mortality to delta smelt and other fish species (Werner et al. 2009), though studies support the potential for chronic effects. One such study reported that exposure of delta smelt to ammonia results in cell membrane destabilization, potentially affecting membrane permeability, enhancing uptake and thus synergistic effects of multiple-contaminant exposure (Connon 2011). Toxicity to copepods was observed in work completed by Teh et al. (2011). In this study there was reduced recruitment of new adults of *P. forbesi* and nauplii survival was negatively associated with concentrations that have been exceeded in measurements taken at Rio Vista (0.36 mg N/L and 0.38 mg N/L) (Teh et al. 2011).

In summary, there is evidence that ammonia levels currently occurring in the Sacramento River have disrupted the historical concentrations and forms of nitrogen in the Bay- Delta system. This shift has transformed the downstream Delta from a nitrate to an ammonia dominated system, and that may have detrimental effects on biological productivity in the LSZ. Although total biomass of zooplankton has not changed substantially in the delta smelt summer habitat, the new species composition may be less beneficial to pelagic fishes (Baxter et al. 2008).

Based on some of the latest information, the most recent NPDES permit for the SRWTP (December 2010) has more stringent effluent limits for ammonia and requires a 20-fold ammonia reduction in the daily maximum concentration (from 45 to 2 parts per million) and a 13-fold reduction in the average monthly concentration (24 to 1.8 parts per million). When implemented, the new limits are expected to reduce ammonium concentrations below values thought to inhibit nitrate uptake by diatoms at all locations in the Delta and Suisun Bay and high chlorophyll *a* concentrations characteristic of the pre-SRWTP should occur more frequently during spring if the low ammonium conditions are restored to Suisun Bay.

> *Level of certainty of this information:* Moderate
>
> Relevance to the LSZ: Elevated ammonia concentrations in the vicinity of the low salinity zone have been shown to reduce primary productivity and chlorophyll production. These levels may limit diatom blooms potentially resulting in a reduction in food for pelagic fishes. While flow increases may affect ammonia levels in the estuary, the mechanism is via dilution rather than a change in total loading, the ultimate issue.

1.2.8 Pesticide inputs remain a major concern, but their effects remain unclear

The current state of knowledge about the effects of contaminants on delta smelt and other pelagic fishes has recently been summarized by Brooks et al. (2011) as part of the IEP POD effort. The available evidence indicates that although acute contaminant toxicity is not a likely cause for the population declines, sublethal stress from multiple factors including pesticides, metals, nutrient-rich effluents, and toxic algal blooms all degrade the habitat of fishes such as delta smelt.

The specific effects of pesticides are not well understood, although effects may be substantial given that agricultural, commercial, and urban purchases of pesticides within the Delta and the upstream watershed averaged 21 million kg annually from 1990 to 2007 (Brooks et al. 2011). Intermittent toxicity has been reported for *Hyalella azteca*, a common invertebrate bioassay species (Weston and Lydy 2010; Werner et al. 2010). Of particular concern is the increase in pyrethroid use (Brooks et al. 2011), which has been shown to be fairly toxic (Brander et al. 2009).

Toxicity may be a key issue for fishes as sublethal contaminant exposure can impair immune function and swimming ability of delta smelt (Connon et al. 2011) and pesticides show sublethal toxicity in surrogate species (Beggel 2010). Delta smelt distribution is known to overlap with several key contaminants (Kuivila and Moon 2004; Brooks et al. 2011) and effects can be substantial depending on the level of exposure (Connon et al. 2010).

> *Level of certainty of this information:* LOW.
>
> Relevance to the LSZ: The new research doesn't provide specific insight into the possible linkages between the LSZ and contaminant exposure. Nonetheless, the body of knowledge continues to point to contaminants as a key background stressor that must be considered in efforts to manage and recover imperiled fishes of the upper San Francisco estuary.

1.2.9 Harmful algal blooms may be having substantial effects on the ecosystem

In recent years, blooms of cyanobacteria ("blue green algae"), particularly the toxin-producing *Microcystis*, have become a regular occurrence in the estuary (Lehman et al. 2005). Blooms of other cyanobacteria such as *Anabaena* and *Aphanizomenon* also have increased, and can co-occur with *Microcystis* (Baxa et al. 2010). These taxa can also produce toxins, but it is unknown if the specific varieties in the estuary are toxin-producers. Toxin-producing strains of *Microcystis* have been documented in the estuary (Lehman et al. 2010a, Baxa et al. 2010), and both toxic and non-toxic strains have been shown to have detrimental effects to zooplankton and fish (Deng et al. 2010; Ger et al. 2010a; Ger et al. 2010b; Lehman et al. 2010a). Additionally, the strain of *Microcystis* in the estuary is genetically distinct from other strains, and may represent a brackish water ecotype that is adapted to higher salinities and low light levels (Moisander et al. 2009). Though cyanobacterial blooms are generally highest upstream of the LSZ, high flows can transport blooms to downstream areas (Lehman et al. 2005).

> *Level of certainty of this information*: MODERATE
>
> *Relevance to the LSZ*: Blooms of potentially harmful cyanobacteria have become regular occurrences in the estuary, particularly in upstream areas of the Delta. Blooms can be transported downstream by high flows, where they may impact the LSZ via the foodweb and toxin production (Lehman et al. 2010a). However, since cyanobacterial blooms tend to be most common in upstream areas, it's likely that the greatest effects on zooplankton and fish will occur in these areas. But because some cyanobacteria can tolerate brackish water, the LSZ may still experience harmful algal blooms.

1.3 Top-Down Effects

Within the upper San Francisco Estuary, predation and entrainment in water diversion facilities are considered major sources of mortality for fishes (Sommer et al. 2007; Baxter et al. 2010). While predation is a natural component of healthy ecosystems, abrupt changes to the physical environment or community structure (e.g. via species introductions) can unbalance established predator-prey relationships. In extreme cases, introduced species have contributed to the local extirpation of native prey (e.g. thicktail chub, Moyle 2002) and predators (e.g. Sacramento perch, Crain and Moyle 2011). The two most abundant introduced predatory fishes in the Delta are striped bass and largemouth bass, and numerous studies on both species have led to recent insights into the role of food limitation (Nobriga 2009), dietary overlap and native prey consumption (Nobriga and Feyrer 2007), and population trends relative to biotic habitat changes (Nobriga et al. 2005, Brown and Michniuk 2007, Baxter et al. 2010). Additional work incorporating new genetic tools has begun to shed light on predation of early life stages of delta smelt as well (Baerwald et al. 2011, Baerwald et al. 2012). Aside from consumption by predatory fishes, another significant source of mortality in the Delta is entrainment into water diversion facilities, especially losses at the SWP and CVP. While well-studied for salmonids (Kimmerer 2008, Clark et al. 2009), the interplay between entrainment and predation remains poorly understood for other species of concern. As such, the total number of fish impacted by both diversion facilities is far larger than the number salvaged, and thus salvage has been determined to be inadequate for gauging entrainment levels (Baxter et al. 2010).

1.3.1 Increases in the abundance of key non-native predators may have important effects on native species' populations, but the magnitude of these effects are unknown

Largemouth bass: Concurrent with the spread of an introduced aquatic plant, *Egeria densa*, the population of largemouth bass, an invasive piscivore, also increased dramatically. This population expansion was likely facilitated by an increase in rearing habitat for juvenile largemouth bass provided by more vegetation cover (Nobriga 2009). The increased abundance of largemouth bass is important because they have been known to alter the abundances of their main prey items in other systems (Mittelbach et al. 1995). In the Delta, largemouth bass are efficient predators in the littoral zone, and relative to striped bass and Sacramento pikeminnow, are the most frequent predators of other fishes, and have the highest incidence of predation on native fish species (Nobriga and Feyrer, 2007).

However, the actual impact of largemouth bass on native species, particularly species of concern such as Chinook salmon and delta smelt, is unknown. As the mobility of largemouth bass is limited and their distribution is restricted to nearshore freshwater habitats, they may have very little overlap with pelagic species. However, recent evidence from studies on delta smelt migration have shown that delta smelt will move into nearshore areas during ebb tides, in order to maintain their upstream migration progress (Bennett and Burau, unpublished data). This nearshore movement may bring delta smelt into close proximity with largemouth bass and *Egeria densa* and increase the chances of predation. However, the delta smelt migration period typically occurs during winter months, when largemouth bass metabolic rates are low and they may not be actively foraging. Furthermore, diet composition studies on largemouth bass have revealed only limited consumption of native species of concern, such as Chinook salmon, delta smelt, and Sacramento splittail (Nobriga and Feyrer 2007). Thus, while studies have clearly shown a relatively recent increase in largemouth bass, we don't have clear evidence that this change has had a significant effect on the populations of key native fishes.

Mississippi silverside: In addition to the population expansion of largemouth bass, Mississippi silversides have been established in the estuary since the mid 1970s (Moyle 2002). Like delta smelt, silversides are a small, slender-bodied fish that generally occupies open-water habitat; however, they are tolerant of broader ranges of temperature and salinity. In a pilot effort to determine whether they predate upon delta smelt larvae, a genetic assay has been developed to detect delta smelt DNA in stomach contents of putative predators (Baerwald et al. 2011). Initial studies have confirmed that silversides indeed consume delta smelt larvae, and that predation may be more common in channel, offshore habitats (Baerwald et al. in press). However, as with largemouth bass, studies to date have not demonstrated a population-level effect of predation by Mississippi silversides on delta smelt or other native fish species. Furthermore, more work is necessary to understand how predation rates vary with both stationary (location, bathymetry) and physical (turbidity, temperature, salinity, etc.) aspects of habitat. Finally, the habitat requirements and population dynamics of Mississippi silversides in the Delta have yet to be determined to understand the extent of their overlap with delta smelt or other species of concern.

Striped bass: Research also continues to examine the potential effects of the apex predator in the LSZ, striped bass. New studies by Loboschefsky et al. (2012) help to address this issue by modeling consumption by striped bass. The results show that predation by sub-adult and adult striped bass is substantial, and varies based on population size. Although the modeling suggested that predation rates were high around the onset of the POD, it is not yet known if predation is an important contributor to trends in pelagic fishes. The studies by Loboschefsky et al. (2012) represent simulations of overall consumption that do not account for resources outside of the estuary (e.g. Pacific Ocean) or attempt to evaluate consumption for rare species like delta and longfin smelts.

> *Level of certainty of this information:* LOW
>
> *Relevance to the LSZ:* When the LSZ overlaps with the distribution of *Egeria densa* and largemouth bass, pelagic fish species such as delta smelt will be in closer proximity with inshore predators. More studies are necessary to understand how Mississippi silverside populations may vary with respect to the location of the LSZ. The modeling studies on striped bass don't evaluate predation losses in specific

regions such as the LSZ, but nonetheless provide perspective on the magnitude of predation. Additional work is needed to examine how variation in predation rates by these fishes may affect the biota of the LSZ.

1.3.2 While export losses remain an ongoing management concern particularly during periods of high entrainment, there is no strong evidence that entrainment is a major recent driver of populations of fishes that occur in the LSZ

The water diversions that are of most concern for fishes in the estuary are the SWP and CVP export facilities, Antioch and Pittsburg power plants, and within-Delta agricultural diversions (Sommer et al. 2007). Of these, the operations of agricultural diversions are the least likely to have had an effect on the POD species because there is no evidence that there has been a substantial change in operations during the past decade (Baxter et al. 2010). With respect to the SWP and CVP water diversions, new studies by Grimaldo et al. (2009b) provide insight into the environmental factors that affect salvage, a count of fish at the water project screens that is considered an index of overall entrainment losses. Grimaldo et al. (2009b) found that adult delta smelt entrainment increased following first flush (first winter rain events) when turbidity increased. Adult delta smelt losses may also be higher during periods when flows in two south Delta channels, Old and Middle Rivers (OMR), are most negative (“reverse flows”). There was also evidence of an interaction of OMR flow with LSZ position (as indexed by X2), suggesting that the distribution of the population in relation to the LSZ prior to migration can be important, but only if OMR flows are negative following first flush events (Baxter et al. 2010).

While export losses remain an ongoing management concern particularly during periods of high entrainment (Kimmerer 2008; Baxter et al. 2010), there is no strong evidence that entrainment is a major recent driver of populations of fishes that occur in the LSZ. Thomson et al. (2010) found that turbidity (discussed as water clarity in that paper) and winter exports were associated with the long-term trend in fall midwater trawl abundance of delta smelt, but could not explain the recent step-decline in abundance during the POD, which began in the early 2000s. Similarly, there was no evidence that exports explained long-term abundance trends in two other LSZ fishes, longfin smelt and young striped bass. In a multiple autoregressive analysis of the same data, Mac Nally et al. (2010) found some evidence for export effects on delta smelt and threadfin shad, but other factors had stronger effects on the suite of POD that inhabit the LSZ (Baxter et al. 2010). These results suggest that entrainment losses from exports did not play a major role in the POD. It is important to note that these studies do not mean that exports did not contribute to the POD since the analyses did not include larval entrainment and the cumulative effects of entrainment of multiple life stages, or the possible importance of episodic events (Baxter et al. 2010).

Level of certainty of this information: MODERATE.

Relevance to the LSZ: Since most entrainment losses occur well upstream of the LSZ, the location of the LSZ may have little direct effect on these types of losses. One as yet untested hypothesis is possible that fall LSZ position may affect the pre-migration distribution of delta smelt, which may in turn affect the subsequent migration pathway and exposure to water diversion (Grimaldo et al. 2009b; USBR 2012). New studies are needed to test this hypothesis. Entrainment risks may be much different for power plants, which are located in or near the LSZ (USBR 2012). However, these facilities have been operated infrequently in recent years, so major effects seem dubious.

1.4 Bottom Up Effects

A well-documented issue is that the upper San Francisco estuary has experienced extensive changes to its food web (Baxter et al. 2010). Higher trophic level production in the open waters of the Delta and Suisun regions is fueled largely by phytoplankton production (Sobczak et al. 2002), but the region has low phytoplankton production and biomass (Cloern and Jassby 2008), and has shown extreme declines (Jassby et al. 2002). Key groups of zooplankton have likewise declined in abundance and biomass, with sharpest changes among calanoid copepods, a primary prey for early life stages of pelagic fishes (Kimmerer and Orsi 1996). The invasion and establishment of the clam *Potamocorbula amurensis* in the late 1980s was followed by a series of major changes in consumers, which likely negatively influenced pelagic fish production (Kimmerer 2002). For example, the clam invasion was followed by a major step-decline in the abundance of the copepod *Eurytemora affinis* possibly due to predation by *Potamocorbula amurensis* (Kimmerer et al. 1994) or a reduction in phytoplankton, its food supply (Baxter et al. 2010).

1.4.1 ***Further evidence of long-term changes in the phytoplankton community***

Analyses of long-term monitoring data from 1975 to 1993 showed a shift from a diatom-dominated community to a flagellate-dominated community, particularly in Suisun Bay (Lehman 2000). More recent analyses showed this trend continuing through 2009, at least for downstream areas (Brown 2009, 2010a). However, some upstream areas still had substantial numbers of diatoms, particularly in the south Delta (Brown et al. 2009; Brown et al. 2010a; Brown et al. 2010b; Brown et al. 2011; Brown 2010, DWR unpublished data). There were also large diatom blooms in Suisun Bay and the LSZ in 2010 in spring and summer (Brown 2011; Brown et al. 2011), similar to blooms seen annually before the introduction of *Potamocorbula amurensis*. These diatom blooms occurred again in spring and fall 2011, though in much lower numbers compared to 2010 (DWR unpublished data). However, the species in the 2010-2011 blooms were not the same as those in the historical blooms; the recent blooms have been dominated by benthic or chain-forming taxa (e.g. *Entomoneis* or *Melosira*, respectively). Historic blooms were generally dominated by single-celled planktonic diatoms (e.g. *Thalassiosira* and *Skeletonema*).

Also, some flagellate groups such as cryptophytes are considered good food sources for zooplankton (Kugrens and Clay 2003), so a shift in the phytoplankton community from diatoms to cryptophytes is not necessarily a loss of food quality. However, changes in the phytoplankton community are likely to have effects on higher trophic levels due to the feeding selectivity of zooplankton. The most common copepod in the estuary, *Limnoithona tetraspina*, was shown to feed exclusively on ciliates and flagellates, and did not consume diatoms at all (Bouley and Kimmerer 2006). Two other copepods that are important prey items for fish (*Eurytemora affinis* and *Pseudodiaptomus forbesi*) fed on flagellates and ciliates, but also consumed diatoms (Bouley and Kimmerer 2006). Additionally, a change to a cyanobacteria-dominated phytoplankton community would be a decline in food quality, as cyanobacteria are considered poor food for zooplankton (Ger et al. 2010a, Ger et al. 2010b). The 2011 spring diatom blooms in Suisun Bay and the LSZ were followed by large cyanobacterial blooms in the fall (DWR unpublished data). How the diatom and cyanobacterial blooms affected zooplankton and fish production in 2011 is still unclear.

> *Level of certainty of this information*: MODERATE
>
> R*elevance to the LSZ*: The LSZ has been shown to be an important habitat for zooplankton and fish (Jassby et al. 1995), so changes in the phytoplankton community in this region are likely to have effects on higher trophic levels. However, these effects could be positive or negative, if the shift in the phytoplankton community is to higher (e.g cryptophytes) or lower (e.g. cyanobacteria) quality food. The importance of food quality for zooplankton has been documented (Bouley and Kimmerer 2006; Ger et al. 2010b). Historically the LSZ was dominated by diatoms, and though diatom blooms have occurred again recently, they are not the same taxa that occurred historically. The effect of this change among diatom taxa on higher trophic levels is not well understood, and needs further exploration.

1.4.2 Further evidence of extreme changes to the zooplankton community

Zooplankton community composition and species abundance in the low salinity zone are well-documented since at least the early 1970s and recent analyses show a clear pattern in the mid- to late-1980s of decreasing zooplankton biomass density that paralleled the decline in the quantity and quality of phytoplankton, an important food for zooplankton (Winder and Jassby

2011). In the same time period, there was a nearly 10-fold drop in the biomass density of mysids (Winder and Jassby 2011). Although overall zooplankton biomass remains low, increases in the relative abundance of copepod species that can flourish under conditions of low phytoplankton productivity (*Limnoithona tetraspina*) or food quality (*Pseudodiaptomus* genus) suggest a direct "bottom-up" influence of the changing phytoplankton community on the zooplankton community (Gould and Kimmerer 2010; Winder and Jassby 2011). An additional concern is that some of the new copepod species may be more resistant to fish predation (Gould and Kimmerer 2010). The introduction of the filter-feeding overbite clam, *Potacorbula amurensis*, is largely credited with changes in the phytoplankton community through direct predation (Alpine and Cloern 1992; Kimmerer et al. 1994; Jassby et al. 2002), and probably had a similar impact on the zooplankton community, thereby limiting zooplankton biomass both directly through predation on early zooplankton life stages and indirectly by competing for shared phytoplankton food resources.

> *Level of certainty of this Information:* HIGH that the zooplankton community continues to change.
>
> *Relevance to the LSZ:* The decline in zooplankton total biomass was characterized by reductions in zooplankton species that are important prey items for fish and an increase in the relative abundance of zooplankton that are more resistant to fish predation (Gould and Kimmerer 2010; Winder and Jassby 2011). The drop in zooplankton biomass density occurred in the late 1980s, suggesting it was not the primary driver of the pelagic fish decline that occurred a decade later in the early 2000s. However, both the reduction in total zooplankton and mysid biomass and the shift to predation-resistant species reduced food availability for pelagic fish in the LSZ, and was likely a contributing factor in the fish decline, as well as a continuing factor limiting recovery of these fishes.

1.4.3 Evidence of further changes in the benthic community

Benthic community composition and abundances have been well-documented in the LSZ since the late 1970's. The benthic community in the LSZ underwent a significant change in the late 1980's with the invasion of the clam *Potamocorbula amurensis*, however, benthic assemblages have been mostly stable since the establishment of *P. amurensis* (Peterson and Vayssières 2010). *P. amurensis* is a voracious filter feeder, and its high abundances in parts of the upper estuary have produced trophic consequences exhibited at all levels of the food web (e.g., bacteria – Werner and Hollibaugh 1993, Hollibaugh and Wong 1996; phytoplankton –Alpine and Cloern 1992, Jassby et al. 2002; zooplankton – Kimmerer et al. 1994, Kimmerer and Orsi 1996, Orsi and Mecum 1996, Winder and Jassby 2010; fishes – Feyrer et al. 2003, Stewart et al. 2004).

Peterson and Vayssières (2010) examined benthic assemblage response to hydrologic variability and found that in years of hydrologic extremes benthic assemblages shifted with salinity, moving down-estuary in years with high outflow, and up estuary during years with low outflow. The strong influence of salinity on the benthic community in the upper estuary is reflected in benthic monitoring data, particularly with respect to *P. amurensis* abundances. In the spring and summer of 2011, a year with high outflows, *P. amurensis* abundances in Grizzly and Suisun Bays were very low relative to the spring and summer of 2009 and 2010, years with lower outflows (Brown et al. 2010; Fuller 2011; Fuller 2012; DWR unpublished data). However, following increases in salinity in Suisun and Grizzly Bays in the fall of 2011, clam abundances increased substantially in this area (DWR unpublished data).

> *Level of certainty of this information:* HIGH that *P. amurensis* significantly changed the benthic community in the LSZ and HIGH that the benthic community shifts up or downstream with changes in salinity.
>
> *Relevance to the LSZ:* Primary production lost to invasive bivalve grazing is likely a key factor limiting productivity in the estuary, and abundances of *P. amurensis* are typically high in the LSZ. It is important to understand the impacts of fluctuating salinities on *P. amurensis* populations.

1.4.4 Additional major changes in the food web

The Siberian prawn *Exopalaemon modestus* was first detected in the San Francisco Estuary in 2000, and was likely introduced during the 1990s (Brown and Hieb in review). It became established in the upper estuary by 2002--based on data from multiple sampling programs, highest numbers occurred from 2002 through 2004. Numbers decreased dramatically after 2004, and the population in the estuary appears to have become be more stabile. However, this may be due to a shift in the population upstream, rather than an actual decrease in shrimp. *E. modestus* is a freshwater species; unlike other caridean shrimp species in the estuary, it does not need brackish water to reproduce. However, it tolerates brackish water, and is regularly observed in Suisun Bay by DFG's Bay Study survey, the only monitoring program that routinely samples caridean shrimp in the estuary. Other than Bay Study, most records of *E. modestus* in the estuary are as bycatch from gears not designed to capture caridean shrimp. Also, the Bay Study does not target shallow habitats (less than 3 m), and does not sample all freshwater areas. Hence, the full population and distribution of *E. modestus* in the estuary are unknown. However, because it is a freshwater species, the bulk of the population is likely centered upstream of the LSZ. Because of its tolerance of brackish water, it is likely to have a regular presence in Suisun Bay and the LSZ. High flow events may also flush large numbers of shrimp downstream to this area.

Level of certainty of this information: LOW

R*elevance to the LSZ*: The Siberian prawn *Exopalaemon modestus* became established in the estuary by 2002; any effects on the POD or LSZ are unknown because other than DFG's Bay Study, little monitoring is done for this species in the LSZ. However, it is regularly caught in Suisun Bay, and has tolerance for brackish water. Additional work needs to be done to study the effects of *E. modestus* in the LSZ.

1.4.5 Identification of food web "hot spots" in other regions

Much of the food web monitoring in the upper San Francisco Estuary has focused on the central Delta, LSZ and Suisun Bay, with particular emphasis on channels. These studies have led to a greater understanding of spatial and temporal variability in production (Lehman and Smith 1991) and documentation of successive invasions of the estuary (Baxter et al. 2010; Winder and Jassby 2010). In recent years, there has been an increasing recognition of the importance of peripheral areas. For example, studies by Schemel et al. (2003), Sommer et al. (2004), and Lehman et al. (2008) indicate that seasonal floodplain may be an important input of primary and secondary production to the estuary. This relative importance of peripheral "hot spots" continues to grow based on new work showing high production in tidal wetlands. Schroeter (2008) showed that smaller channels of Suisun Marsh contain relatively high levels of invertebrates, which may help to explain the occurrence of large numbers of young striped bass. More recently, Lehman et al. (2010b) studied Liberty Island, the "newest" large habitat in the Delta. This large area of tidal wetlands was formed by a flood event in 1997 that inundated the island, leading to the formation of open water and emergent marsh. Their studies revealed that exports of organic and inorganic production from Liberty Island vary tidally and seasonally.

Level of certainty of this Information: LOW-MODERATE.

Relevance to the LSZ: There is substantial new evidence that regions outside of the LSZ are much more important than previously understood. Hence, effective management of the estuary must consider not only the LSZ, but also peripheral habitats that provide fish habitat and serve as "food banks" for the estuary.

2 Effects of Invasive Species

Take Home Points:

- *Invasive species are already having severe effects on the aquatic ecosystem.*

Suggested Short Term and Long Term Actions:

- *Efforts to deal with invasive species should include: detailed monitoring; prevention programs; and response plans.*

Introductions of invasive species have completely altered not only the biota of the estuary, but the very landscape. The high level of species invasions and associated impacts have been discussed extensively by previous studies such as Cohen and Carleton (1998) and Matern et al. (2002). The results of much of the new research were described above, including the following studies.

General Species Effects:

Baxter et al. (2010); BDCP Effects Analysis (BDCP 2012b)

Harmful Algal Blooms:

Lehman et al. (2010); Baxa et al. (2010); Deng et al.(2010); Ger et al. (2010a,b); Moisander et al. (2009)

Benthos:

Peterson and Vayssieres (2010); Brown et al. (2010a); Fuller (2011); Fuller (2012)

Zooplankton:

Gould and Kimmerer (2010); Winder and Jassby (2010)

SAV and the inshore fish community:

Grimaldo et al. (2009a); Santos et al. (2011; 2012); Hestir (2010)

Pelagic Fishes:

Threadfin Shad--Feyrer et al. (2009)

Striped bass—Loboschefsky et al. (2012); Sommer et al. (2011b)

POD Fishes-- MacNally et al. (2010); Thomson et al. (2010)

The latest studies continue to show that the effects of these species are extensive and severe. Studies such as Baxter et al. (2010) and Moyle et al. (2008) suggest that changes in salinity variation may affect the persistence of some invasives. Similarly, Glibert et al. (2011) and Baxter et al. (2010) hypothesize that nutrient inputs can alter the phytoplankton community towards harmful or less-nutritious types, which may in turn affect the zooplankton community.

Level of certainty of this Information:
HIGH that invasive species are undermining the aquatic ecosystem in the Bay-Delta and will continue to do so in the future.
LOW in our ability to predict future changes to the ecosystem from invasive species. See below for possible approaches to deal with uncertainty.

Relevance to the LSZ: There is good evidence that the response of some of the POD fishes to flow has become muted in recent years (Kimmerer 2002; Sommer et al. 2007; Baxter et al. 2010). This does not mean that there is no longer a community response to flow; rather, there is less "bang for buck" as compared to the historical response to higher flow conditions. As described in Kimmerer et al. (2002) and Baxter et al. (2010), invasive species appear to be a major reason for this change. Indeed, Baxter et al. (2010) suggest that there has been a major regime shift in the ecosystem that may be difficult to reverse. If true, current management of the LSZ (e.g. spring X2) may still contribute to modest variation in the abundance of estuarine fishes, but the ecosystem will show little major improvement without large and bold actions to shift away from the current ecological regime.

3 Effects of Climate Change

Take Home Points:

- *Ongoing changes in climate mean that past climate and hydrology alone are unlikely to be good predictors of future conditions.*
- *The vulnerabilities of the current system will be exacerbated by climate change—we need to improve our planning for it and take actions that improve the system's resilience to expected changes.*
- *Expected major changes include flooding of delta islands from sea level rise, associated salinity increases in the delta, earlier snowmelt runoff and changes in hydrology, and increased temperature.*
- *Temperature increases are a particular concern for sensitive species such as delta smelt.*

Suggested Short Term Actions:

- *New management actions should not assume that long-term historical hydrology (e.g. unimpaired flow) applies to current conditions. Recent conditions and climate modeling may provide a better indication of what to expect in the near-term.*

- *Regulatory thresholds should be established with consideration of changes in climate and hydrology that have already occurred and that are projected to occur in the future.*

Suggested Long Term Actions:

- *Programs to improve and protect ecosystem conditions will be most likely to meet their objectives if they are designed to function within altered climatic conditions rather than today's climate and hydrology. For example, delta planning efforts such as BDCP are being designed to function under a range of future climate conditions—not just the conditions that exist today.*
- *Similar planning is needed for many other aspects of Delta management.*

Climate change represents one of the greatest challenges to the management of the resources of the estuary. Three major effects include alteration of runoff patterns and precipitation, sea level rise, and temperature increases. Studies to date already demonstrate a trend toward more Sierra Nevada precipitation falling as rain and less falling as snow (Roos 1987; 1991 cited in Baxter et al. 2010; Knowles and Cayan 2002; 2004), increasing the likelihood of flooding and reducing our flexibility to seasonally store water. Precipitation is also expected to become more variable, with more extreme wet and dry conditions. In turn, altered hydrographs affect fish life history, which is usually tied to historical runoff patterns (Moyle 2002; Brown and Bauer 2009). Sea level, the second major effect, has been rising since the end of the last ice age and shows a significant acceleration in the past several decades (NRC 2012b). Sea level rise is known to cause increase salinity intrusion, which is expected to force the LSZ inland. As described above, changes in the position of the LSZ (e.g. X2) have the effect of shifting the distribution and habitat of delta fishes. Similarly, sea level rise is expected to increase the likelihood of levee failures (Mount and Twiss 2005), an additional factor that is expected to change the geographic location of the LSZ and its general bathymetry (Lund et al. 2007; 2008). Perhaps the greatest threat to the fishes of the Bay-Delta is the predicted warmer air temperatures in the region (Dettinger 2005). Although water temperatures do not currently have a strong detectable influence on the distributions of POD fishes (Feyrer et al. 2007), this variable is of extreme concern for sensitive species such as delta smelt (Swanson et al. 2000; Nobriga et al. 2008). Some of the most recent literature is summarized below.

3.1 Continued evidence that runoff patterns and precipitation will change

One of the most comprehensive studies to date is an investigation by Cloern et al. (2011), who used a series of linked models under two contrasting scenarios of climate change (high and moderate warming). Their studies confirmed major changes to hydrology, habitat quality, salinity, precipitation, runoff, and snowmelt contribution to runoff over the 21st century. They concluded that subsequent changes to the biological community are inevitable.

BDCP (2012c) provides a detailed modeling and analysis of current and expected future delta hydrology with current infrastructure, ecological conditions, and operations and with proposed improvements in infrastructure, ecological restoration, and proposed future operations[1]. These modeling studies include estimates of future flow patterns and associated species effects. Changes in monthly and annual runoff under projected climate conditions modeled for the BDCP studies, reflect a general trend of snowpack runoff shifting from spring and early summer to rainfall runoff in the winter months. Because this shifts results in additional runoff entering the major multi-purpose reservoirs in the Delta watershed (Shasta, Oroville, Folsom, Millerton) during months that these reservoirs are operated for flood protection, there is limited ability to store the runoff and much of it would have to be released and would not be available later in the year when it is needed. Thus, these changes in snowpack accumulation and snowmelt runoff result in differences in downstream flows and Delta inflows, and have implications for project operations. Projected shifts in the timing and volume of flow entering and exiting the Delta has broad ecological impacts including potential alteration to biologically relevant transport flows, migration cues and timing, as well as availability of and access to habitat. Furthermore, these projected shifts in runoff patterns will impact different species to different degrees.

In addition to the shifts in runoff patterns, total precipitation is also expected to become more variable with both more intense storm events and more frequent drier periods and prolonged droughts. The frequency of atmospheric river storm events will increase resulting in greater flood magnitudes (Dettinger, 2011). These events will put additional stress on Delta levees, contributing to an increase in levee breaches and failure, which as discussed above can change the geographic location of the LSZ and its general bathymetry (Lund et al. 2007; 2008). At the same time as storms are getting more frequent and extreme, the overall average annual precipitation in both Central and Southern California is expected to decrease by the mid to late 21st century. Half of the projections of future climate change show that the 30-year average precipitation will decline by more than 10 percent below the historical average by late century (CCCC, 2012). Drier conditions and an increasing frequency of drought, including prolonged droughts, will contribute to increased water temperatures, greater salinity intrusion, reduced water quality and changes in location of the LSZ.

Feyrer et al. (2010) developed a model to predict delta smelt habitat quality in response to changes in X2 based on simulated future hydrology. Data from several scenarios of climate change showed reduced habitat suitability as a result of salinity intrusion (Feyrer et al. 2010). These and other climate-related changes have also been discussed in Baxter et al. (2010) and Sommer and Mejia (In review).

---

[1] A summary of the methodology used by BDCP to develop projections of future climate change and use those projections for the effects analysis of the proposed project and alternatives is described in "Climate Change Characterization and Analysis in California Water Resources Planning Studies" (Khan and Schwarz, 2010).

Level of certainty of this Information:

MODERATE-HIGH that future runoff conditions will be different.
LOW-MODERATE for the specific responses of the biota.

Relevance to the LSZ: Changes in runoff amount and/or timing that affect the area of the LSZ are highly likely. Operational management to protect this habitat will become more constrained as runoff timing shifts earlier and conflicts with flood control operations at multi-use facilities. Future efforts to protect LSZ habitat could have increasingly large trade-offs with other system benefits.

3.2 Continued evidence that sea level rise will have substantial effects

Rising mean sea level is expected as a result of global warming. As much as 167 cm (66 inches) of sea level rise is projected for the California coast and Delta region by 2100 (NRC 2012b). In 2012, the National Research Council (NRC) conducted an exhaustive review of existing global sea level rise science and projections and produced a definitive study of sea level rise projections for the west coast of the United States. While several other reports and journal articles have been issued which provide projections of global sea level rise (IPCC 2007; Vermeer and Rahmstorf 2009; Pfeffer et al. 2008; Rahmstorf 2007) this is the first comprehensive study for the west coast of the United States which accounts for local land surface movements and ocean current effects that may result in sea level rise values for California that deviate from global values. Table 1 below provides NRC (2012b) projections for sea level rise values for the California coast in the Delta region. Projections of sea level rise used in the analysis conducted for BDCP discussed above and below are within the range of potential sea level rise projected by NRC (2012b).

Table 1. Sea Level Rise Projections for San Francisco and Delta Region 2030, 2050, and 2100

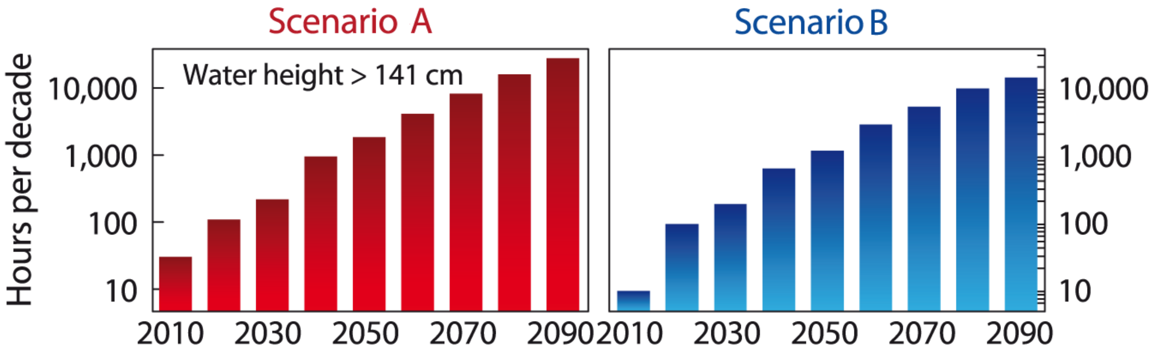
		2030		2050		2100	
		Projection	Range	Projection	Range	Projection	Range
Projected Sea Level Rise at San Francisco	cm	14.4 ± 5.0	4.3–29.7	28.0 ± 9.2	12.3–60.8	91.9 ± 25.5	42.4–166.4
	in	5.7±2	1.7-11.7	11±3.6	4.84-23.9	36.2±10	16.7-65.5

Source: NRC, 2012b, projected sea levels are increases from values for the year 2000

A rising sea level will impact the Delta in two important ways: 1) increase the risk of overtopping and other forms of levee failure and 2) increased saline/brackish tidal pressure, which if not counteracted by increases in freshwater outflows will lead to increased salinity intrusion and higher salinity levels in the Delta.

Higher sea levels increase the risk of levee failure by producing higher hydrostatic loads against levees and by increasing internal seepage gradients. Most of the land in the Delta is below sea level as a consequence of ongoing subsidence. Rising sea levels would place more pressure on the Delta's already fragile levee system, and as a consequence could increase the risk of levee breaches. Broad areas of the Delta are highly susceptible to inundation (Knowles 2010). Moreover, economic considerations may reduce the likelihood of repairing such failures, given economic considerations (Suddeth et al. 2010). High water events such as storm surges and seasonal high tides could further increase the risks of levee failure. Since sea level rise increases the mean sea level, it raises not just the level of the highest sea stands but also increases the amount of time that levees are exposed to higher sea stands as described below.

Cloern et al. (2011) evaluated the extent to which extreme water levels might increase in the future. As indicated in Figure 1, both scenarios result in marked increases in the frequency of extreme water heights 1.41 m or above mean sea level. Historically, sea levels have only exceed 1.4 m for approximately 8 hours per decade in San Francisco Bay, Cloern et al. (2011) project that sea levels in 2050 will exceed 1.41 m 1,200 to 2,000 hours per decade and by the end of century will exceed 1.41 m 15,000 to 30,000 hours per decade (note that the "Hours per decade" scale in Figure 1 is logarithmic). Although the projected increase in water heights addressed in the cited study was modeled for the San Francisco Bay, it correlates to increased, though somewhat attenuated, water heights within the Delta.



Source: Cloern et al. (2011), Sceanrio A reflects higher climate change and scenario B reflects less climate change

Figure 1. Increases in Duration of High Water in the Bay-Delta System

Higher sea levels also increase the hydrostatic pressure of sea water flowing in from the Pacific Ocean and San Francisco Bay. This higher pressure can increase salinity in the Delta's inland waterways if not counter acted by increased outflows of freshwater. Greater inflows to the Delta of freshwater would likely be achieved by releasing greater amounts of water from upstream reservoirs. This would reduce the amount of water available for other uses as this additional water would end up as Delta outflow to the ocean. However, even if freshwater inflows to the Delta were increased to counteract the effect of sea level rise, increased salinity intrusion could still occur in deeper more stratified channels by increasing density driven-flows (Fleenor et al. 2008). Conversely, if freshwater inflows were not increased to counteract higher sea levels, additional saline water would flow deeper into the Delta and would increase the salinity in areas of the Delta that are already brackish. The X2 position would move inland.

Chen et al. (2010) evaluated the effect of a 1 to 3 foot increase in sea level rise (with no change in Delta inflow hydrology) on Delta water quality and drinking water treatment by modeling salinity (and other water quality metrics) at multiple Delta intake locations. Table 2 shows that for Banks Pumping Plant, a 1-foot increase in sea level (about the level of increase projected for 2050) has a minimal impact on salinity at the low end of the impact range. Salinity increased by about 30% for average impacts, and at the high end of impacts salinity nearly doubled. A 3-foot increase in sea level (about the level of increase projected for 2100) would significantly diminish water quality with conductance and Bromide concentrations increasing by two to three times baseline sea level conditions. Another study, Fleenor et al. (2008) found similar results, predicting that a one-foot sea level rise would increase the annual average salinity concentration at the Clifton Court Forebay (which supplies the Banks Pumping Plant) by approximately 4 to 26 percent, with even higher concentrations associated with a three-foot rise.

Table 2
Salinity Levels at the Banks Pumping Plant Associated with Sea Level Rise

Condition	**Conductance (µS cm^{-1})**			**Bromide (mg L^{-1})**		
	Low	**Average**	**High**	**Low**	**Average**	**High**
Current (2003-2007)	125	355	671	0.03	0.15	0.41
1-foot Sea Level Rise	126	455	1,166	0.03	0.16	0.85
3-foot Sea Level Rise	126	741	2,120	0.03	0.50	1.64

µS cm-1 = microsiemens per centimeter
mg L-1 = milligrams per liter
Source: Chen et al. 2010

Level of certainty of this Information:
HIGH that sea level rise will increase the risks of levee failure and associated seawater intrusion.
LOW-MODERATE for the specific responses of the biota.

Relevance to the LSZ: As for runoff patterns (above), changes in sea level that affect the LSZ are inevitable. Efforts to protect this habitat are unlikely to be successful unless they include a strong focus on expected future conditions.

3.3 Continued evidence that increasing water temperatures will degrade the habitat of key Bay-Delta resources

The general effects of warmer future conditions have recently been reviewed in Baxter et al. (2009), BDCP (2012c), and Sommer and Mejia (In review). Modeling results from the BDCP Effects Analysis, which accounted for climate change projections, estimate an annual average Delta water temperature increase, in the ~2025 timeframe, ranging from 0.32°C to 0.54°C and 0.91°C to 1.57°C in the ~2060 timeframe. The increases were variable regionally and seasonally, but would cumulatively reduce quantity and quality of habitat for covered aquatic species. Additionally, the results support the conclusion that on average higher temperatures would increase the metabolic demand for aquatic species, and could result in a more limited spawning period for delta smelt. Furthermore, the estimates showed an average increase in the number of both stressful and lethal temperature-days per year, for endemic Delta species such as delta and longfin smelt, as we move into the future.

The results of Cloern et al. (2011) are particularly disturbing as they evaluate the responses of several biological indicators to climate change. The results suggest that delta smelt and Chinook salmon will be highly susceptible to these adverse changes. The Cloern et al. (2011) study incorporates the work of Wagner et al. (2011), who found that the future will include a dramatic increase in the number of days with lethal (>25 C degrees) temperatures.

> *Level of certainty of this Information:*
> HIGH that future temperatures will increase.
> MODERATE-HIGH for the specific responses of the biota.
>
> *Relevance to the LSZ:* As for runoff patterns and sea level (above), changes in temperature that affect the biota of the LSZ are inevitable. Efforts to protect this habitat are unlikely to be successful unless they include a strong focus on expected future conditions.

3.4 New evidence that ocean patterns affect the resources of the Bay-Delta

Although the focus of the current review is the LSZ, it is important to consider how global conditions may affect the estuary as a whole. New work by Cloern et al. (2010) suggests that broad communities of the lower estuary may be affected by large scale changes in oceanic currents. Like climate, ocean currents are expected to change substantially under future conditions.

> *Level of certainty of this Information:*
> MODERATE that coastal currents affect the resources of the estuary.
> LOW regarding how future changes will affect the responses of LSZ biota.

Relevance to the LSZ: Management of the LSZ should not only consider temporal changes (e.g. future climate change), but also the broader geography of the lower estuary and its watershed.

3.5 Additional considerations and recommendations related to climate change

Past SWRCB actions and analysis of flow criteria and critical flow thresholds have relied on streamflow datasets such as the California Central Valley Unimpaired Flow Data (DWR 2006). This dataset and others like it document historical flow conditions and provide estimates of what flow conditions might have been had the watersheds not been altered by human development.

Use of these historical datasets as an indicator of future flow conditions is based on the assumption of hydrologic stationarity. This assumption has been shown to be invalid for at least some major Central Valley watersheds (Wang et al. 2011). Identifiable trends of changing hydrology are now visible in observations of historical runoff and all expectations are that these trends will continue and are likely to accelerate.

While historically observed conditions continue to provide highly valuable data for projection of future conditions, continued reliance on these observations alone will lead to flawed projections of future conditions that could result in over or under regulation of critical conditions.

DWR has attempted to move beyond the assumption of stationarity and analyze the impacts of climate change on water resources systems in a number of ways. In 2010, DWR completed a comprehensive study of the different approaches it and its partner agencies had taken to address climate change in water resources planning studies (Khan and Schwarz, 2010). The study revealed that a number of different approaches had been used and that each had strengths and weakness. Since the completion of the 2010 study, DWR has embarked on a focused effort to develop an improved approach to addressing climate change. This process is being guided by an independent board of experts drawn from around the country (and Canada) and including scientists, engineers, hydrologists, lawyers, and local water managers drawn from the academic community, private sector, and government. This board will advise DWR on all aspects of the way DWR deals with climate change. One of their first tasks will be to help DWR develop appropriate scenarios of future climate change and procedures for their use in water resource planning and management applications. DWR expects that the climate change advisory board will have largely completed the task of scenario development by early 2013. These scenarios will provide a sound scientific basis for incorporation of changes in historical hydrology as a result of climate change and may be extremely helpful in assisting the SWRCB with addressing these changes for regulatory actions. All meetings of the DWR climate change advisory board are open to the public and the SWRCB is encouraged to attend these meetings to learn more about the effort. (http://www.water.ca.gov/climatechange/cctag.cfm)

4. Dealing with Uncertainty

Take Home Points:

- *Existing year-to-year precipitation and runoff patterns in California are highly variable.*
- *The fact that there is substantial uncertainty about future ecosystem conditions is inescapable.*
- *Uncertainty will continue to challenge the balancing of water resources for beneficial uses over the near-term and long-term.*
- *Operational flexibility and detailed monitoring are critical in being able to respond to future changes.*
- *Adoption of higher flow requirements will require trade-offs with other beneficial uses of water, which will require substantial consideration of the level of certainty when reaching a balanced approach to the Bay-Delta Plan.*

Suggested Near- and Long-Term Action:

- *Integrated planning efforts such as the California Water Plan are needed to guide resource use in the state.*
- *Adaptive management strategies need to be developed for current and future operations.*
- *Adaptive management will be most successful when implemented in a well-defined, multi-party setting, which includes peer review, feedback loops, and a clear decision-making framework.*
- *Conceptual models and hypothesis are critical to guide these efforts.*
- *Efforts such as FLaSH and BDCP provide examples of possible near- and longer-term science-based management approaches, respectively.*
- *Greater operational flexibility as provided by multiple water project intake locations would provide greater opportunities for a balanced approach through the adaptive management process.*

As discussed in the previous sections, there is still substantial uncertainty about our understanding of the LSZ and its biota. This uncertainty includes both how the system currently works, but also how it will function in the future given climate change and continued waves of species introductions. Obviously, the high degree of uncertainty creates major challenges for resource managers. Despite the challenges, there are logical approaches to manage for uncertainty. In our role as managers of the State of California's water resources, DWR has had to deal with uncertainty on a regular basis to reliably deliver water for municipal and agricultural uses while protecting the ecosystem. For example, since at least 2006 DWR has incorporated climate change into its planning activities. Here, we describe DWR's approach to dealing with short-term and longer-term uncertainty in water supply. We also include information about how we incorporate scientific information into the decision process. Our hope is that this insight will be useful to SWRCB in its own approach to planning for current and future uncertainty.

4.1 Near-Term Management of Water Resources

4.1.1 Managing Hydrologic Uncertainty

California's hydrology is uniquely variable in the United States. For most of the country the annual standard deviation of precipitation is a small fraction of the mean. However, in California the standard deviation is larger relative to the mean than anywhere else in the country. To a limited extent the large water projects provide a damper on the effects of this highly variable annual fluctuation. Catastrophic flooding effects are greatly reduced in wetter years. Droughts and salt water intrusion are not as severe in drier years due to project operations. However, river flows and Delta outflow conditions continue to vary significantly, on an intra-seasonal basis as well as on an annual basis. "Average" or "typical" hydrology is an illusion. Although historical hydrologic years may share annual volumes that are similar, no two years are identical in the monthly distribution. This exceptional variability adds a significantly high level of uncertainty when testing hypotheses based on short term data sets.

The use of statistical methods as applied to historical information in the form of exceedence plots are necessary to estimate expected runoff volumes. Hydrology is "averaged" and "normalized" as a necessary distortion to allow for practical water resource planning and management activities. Conservative estimates of water supply availability must be utilized in order to prudently apportion water uses over the course of a year. Water delivery forecasts must be apportioned to the water supply that remains after first meeting all regulatory requirements and while considering all physical conveyance and storage limitations of the system.

4.1.2 Ecological and Regulatory Uncertainty

In addition to the inherent hydrologic uncertainty of the water system, the next greatest source of ambiguity is the continuing uncertainty related to the implementation of the latest biological opinions issued by United States Fish and Wildlife Service and the National Marine Fisheries Service on the operations of the Central Valley Project and State Water Project.

The actions within these biological opinions rely heavily on a real-time adaptive approach on setting highly variable flow targets within the confines of a range of possibilities. The process for setting these targets is complex and resource intensive. Interagency groups of scientists, engineers, and resource managers collect, process, distribute, and analyze large qualities of real-time data on flow, water quality, and fish distributions to inform the decision making process.

Since 2009, both biological opinions were litigated and have been remanded by the lower Courts. Both are currently being reworked and are subject to NEPA analysis. Because of the ongoing uncertainty in the ecological sciences, the final result of these processes are greatly in doubt.

In the interim, the Court adopted an interim remedy order for fall X2 operations in 2011 and parties to the litigation have enacted other annual operating agreements for other actions in an attempt to provide adequate protection for listed species while minimizing water supply impacts and producing experimental data to help inform future management decisions. These alternative actions have varied significantly from those issued in the litigated biological opinions.

4.1.3 Beneficial Use Trade-Offs

The regulatory undulations as described in the previous section have resulted in predictable and measurable trade-offs with other beneficial uses of water. To a large extent the allocation of resources on a year-to-year basis is a zero sum game. The adoption of a regulation whose intent is to benefit one species will likely have some adverse effect to other species or the water supply for agricultural or municipal and industrial users. When making these decisions it would seem prudent to give substantial consideration to the level of certainty regarding the potential benefits and costs associated with such changes in order to reach a balanced objective.

4.2 Longer -Term Planning of Water Resources

Good examples of how DWR addresses uncertainty over the longer-term are the California Water Plan and the Bay-Delta Conservation Plan Effects Analysis. The basic approach taken by each of these programs is summarized below.

4.2.1 California Water Plan

Every five years DWR prepares the California Water Plan, a major tool to provide guidance toward meeting statewide and regional water challenges. As an example, the 2009 California Water Plan Update (CDWR 2009) is made up of three major volumes;

1) Volume 1 presents a strategic plan for all aspects of water management in California with a vision, mission, goals, recommendations, and implementation plan.

In addition, a chapter in this volume identifies companion State plans that have a direct connection with the Water Plan. The chapter on California Water Today outlines California's extreme and variable resources and details water uses and supplies on a statewide basis. Meeting these challenges requires that we account for and reduce uncertainty and risk and that our investments make our water management systems, flood protection systems, and ecosystems more sustainable. This approach to managing our resources through 2050 is outlined in the chapter on Managing an Uncertain Future which describes the basics behind the development of scenarios for Update 2009 and some of the statewide drivers, and presents three narrative scenarios for conditions through 2050.This approach also requires that the water community have improved water resources information and analysis and a chapter includes some key actions for making those improvements.

2) Volume 2 describes resource management strategies that can help to meet the various water management objectives of each region and statewide. With these strategies and through the process of integrated regional water management, regional managers can group and implement strategies into response packages, crafting them to provide multiple water and resource benefits.

3) Volume 3 includes a set of 12 regional reports with each describing the wide variety of watersheds and water conditions, population and land use, and activities that influence a region's water use and supply reliability. The reports focus on California's 10 hydrologic regions, which correspond to the state's major water drainage basins, and two important regional areas that overlie hydrologic boundaries but encompass communities that share common water issues or interests: the Sacramento-San Joaquin River Delta region and the Mountain Counties area, which includes the foothills and mountains of the western slope of the Sierra Nevada and a portion of the Cascade Range. Each regional booklet includes a water balance summary—water use and water supply—for years 1998 through 2005 and scenario results that project the region's water needs through year 2050 with the use of three alternative future scenarios and 12 climate change scenarios.

The California Water Plan collaboration process is as important as the document it produces. DWR improved interagency coordination to provide a statewide perspective on Water Plan issues by creating the California Water Plan Steering Committee. Committee membership represents 28 State government agencies with jurisdictions over different aspects of California's water resources and integrates their companion planning documents. In addition, a 47 member public advisory committee, expanded regional outreach though a recently formed regional forum process, and the formation of a Tribal Advisory Committee assures broad participation in plan preparation.

As described above, managing for an uncertain future is one of the areas of focus for the California Water Plan. Future scenarios can be used to help us better understand the implications of future conditions on water management. The Water Plan considers three plausible, yet very different, future scenarios as a way to consider uncertainty and risk and to improve resource sustainability. One scenario is a projection of current trends. Another scenario considers lower population growth and other factors that may require less intensive use of resources. A third scenario covers the possibility of more expansive population growth and other factors that would result in more intensive use of resources.

The concept is to not plan for any one given future as in past water plan updates, but to look at how each future scenario could be managed. Certain combinations of management strategies, or response packages, may prove to be appropriate regardless of the future conditions. This is especially true if the response packages have a degree of adaptability to differing conditions that may develop. A general description of the scenarios can be found later in this chapter.

For Update 2009, we evaluated different ways of managing water in California depending on different future conditions for different regions of the state. The ultimate goal is to evaluate how alternative regional response packages, or combinations of resource management strategies from Volume 2, perform under different future conditions. The different future conditions are described as future scenarios. Together the response packages and future scenarios show what management options could provide for sustainability of resources and ways to manage uncertainty and risk at a regional level.

The Water Plan has made significant improvements to the scenarios by considering the potential effect of long-term climate change on future water demands. More work will be required in the next Water Plan update to refine this information based on the differing conditions and opportunities in the various regions.

4.2.2 Bay Delta Conservation Plan Effects Analysis

The Bay Delta Conservation Plan (BDCP 2012c) is another example of DWR's efforts to incorporate climate change into its programs. As part of DWR's planning process and the development of the BDCP, there was extensive use of climate and operations models to examine potential changes under future conditions at two distinct time-frames, approximately

2025 (Early Long Term) and 2060 (Late Long Term). The modeling included several scenarios including possible fall flow requirements (see FLaSH below). These points in time were chosen to represent important milestones in the course of BDCP and also to provide points along the estimated climate change trajectory to investigate changed conditions with important ramifications for covered species. For BDCP planning scenarios, projections of climate change were made on the basis of Global Climate Model (GCM) simulations, under a range of future emissions scenarios. These climate projections were used to model expected changes in hydrology. Hydrology and air temperature projections together with sea level rise projections (12-18 cm for 2025 and 30-60 cm at 2060) were then used to model future SWP and CVP operations and Delta conditions using CALSIM II and DSM2.

Summary results include:

- high temperature events are expected to become more common upstream of the Delta, resulting in stress to covered species and potential degradation in amount and quality of rearing habitat;
- combined effects of rising sea level, greater salinity intrusion and warming Delta waters will adversely affect aquatic species covered under State and federal Endangered Species Acts and the quality of their habitat.

4.3 Adaptive Management and the Use of Scientific Information for Management

Adaptive management is one of the most widely accepted approaches to deal with uncertainty in resource management. Here we describe some examples to illustrate the ways in which DWR addresses adaptive management through the use of scientific information. These large scale examples may provide some guidance to the SWRCB staff and members as they consider incorporating adaptive management into SWRCB programs.

4.3.1 BDCP Decision Tree and Adaptive Management Plan

Adaptive management is strongly embraced by the Bay Delta Conservation Plan (BDCP) under development by DWR, Reclamation, and other Federal and State agencies. The Conservation Strategy put forward by BDCP includes measures to restore habitat, increase productivity, and improve flow conditions with a holistic ecosystem approach. Of critical importance for this approach is a rigorous, scientifically-based adaptive management and monitoring plan (BDCP 2012d). An Adaptive Management Team, including representatives from State and Federal resource agencies, IEP, Delta Science Panel, and others, will be responsible for developing and managing the monitoring and research program, the science review process, and implementing the adaptive management process. The BDCP adaptive management approach attempts to build upon current Delta specific conceptual models, with directed research focused on answering critical questions, informing management decisions, and providing a framework for incorporating new understanding. This approach incorporates the flexibility needed for hypothesis testing, comparing effectiveness of alternative conservation measures, and responding to unforeseen future ecosystem changes. A "Decision Tree" approach will begin immediately upon approval to proceed with the BDCP (10 to 15 years prior to operation of the conveyance facility) and be utilized to address the ability of alternative operating criteria, in combination with other conservation measures, to meet biological goals and objectives and water supply reliability, through the testing of specific scientific hypotheses. Information gained through this process will be used to refine operations and to feed into the broader Adaptive Management program and future operations under alternative conveyance. Similarly, information gathered through near-term restoration and monitoring efforts, being developed by DWR and others, will be synthesized and used to inform future projects and conservation measures.

4.3.2 Fall Low Salinity Habitat (FLaSH) Adaptive Management Plan

While DWR has serious reservations about the "Fall Action" in RPA Component 3 of the 2008 OCAP Delta Smelt Biological Opinion (USFWS 2008) because of its projected high water supply costs and low certainty about biological benefits, we have been active in addressing uncertainties about the action using a scientific approach and through computer modeling analyses. Our use of modeling analyses for the BDCP included scenarios with and without the Fall Action (described above). In addition, DWR has been a major partner in the Fall Low Salinity Habitat (FLaSH) study program developed by IEP.

The FLaSH Adaptive Management Plan (USBR 2012) included a "Set up" phase which described the following:

- Specific goals and objectives.
- The organizational process for the program.
- Conceptual models.
- Specific predictions about the expected response of the ecosystem to fall flow changes.
- A science plan for how the predictions will be evaluated through monitoring and focused research studies.

FLaSH also includes an "Iterative Element" that will:

- Incorporate input from different groups to establish alternatives.
- Conduct peer reviews of the plan.
- Conduct annual peer review of the results.

As described in Section 1.2.2, the FLaSH study has just completed its first year. A panel of experts is reviewing the results. Although formal conclusions relating to the results are not available, some of the initial results suggest that the responses of the ecosystem to high fall 2012 flows did not necessarily follow the predictions in the FLaSH Adaptive Management Plan (USBR 2012). Hence, several aspects of the conceptual model need to be reevaluated in order to reduce uncertainty about the efficacy of the experimental action. This information will be taken into account in a suite of studies over the next several years, which are intended to progressively reduce uncertainty.

4.3.3 The importance of research and monitoring to reduce uncertainty

DWR places high value on the use of scientific information to reduce uncertainty. The range of data collected is broad, including hydrologic monitoring, as well as ecological monitoring and research.

Hydrologic Monitoring: DWR's management of the state's water resources depends on a sophisticated network of monitoring stations to provide real-time data. The current monitoring network spans the state and includes reservoirs, streams, rivers, canals, and diversions. The type of technology used ranges from simple stage recordings in streams to acoustic doppler current profilers that provide detailed measurements of net flows in rivers and tidal channels. To maximize the utility of this information to resource managers, much of the data are telemetered and are available on the DWR's California Data Exchange Center (http://cdec.water.ca.gov).

Ecological Research and Monitoring: One of the most intensive programs supported by DWR is the Interagency Ecological Program, a multi-agency effort to monitor and study the Bay-Delta. DWR's contributions include a major portion of the financial support for IEP, management support to the IEP Management Team and Coordinators, support staff, laboratories and vessels, groups dedicated to applied scientific studies (e.g. http://www.water.ca.gov/aes), and one of the most extensive estuarine monitoring programs in the world, the Environmental Monitoring Program (EMP--http://www.water.ca.gov/iep/activities/emp.cfm).

References

Alpine, A. E. and J.E. Cloern. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnology and Oceanography 37:946-955.

Atwater, B. F., S.G. Conard, J. N. Dowden, C.W. Hedel, R.L. MacDonald, and W. Savage. 1979. History, landforms and vegetation of the estuary's tidal marshes. Pages 347-385 in T.J.

Conomos, editor. San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science, San Francisco, CA.

Baerwald, M. R., B. M. Schreier, G. Schumer, and B. May. (2012) Detection of threatened Delta smelt in the gut contents of the invasive Mississippi silverside in the San Francisco estuary using TaqMan assays. *Transactions of the American Fisheries Society* in press.

Baerwald, M. R., G. Schumer, B. M. Schreier, and B. May. (2011) TaqMan assays for the genetic identification of delta smelt (*Hypomesus transpacificus*) and Wakasagi smelt (*Hypomesus nipponensis*). *Molecular Ecology Resources*, 11:784-785.

Baxa, D. V., T. Kurobe, K. A. Ger, P. W. Lehman and S. J. Teh. 2010. Estimating the abundance of toxic Microcystis in the San Francisco Estuary using quantitative real-time PCR. Harmful Algae 9: 342349.

Baxter R., R. Breuer, L. Brown, L. Conrad, F. Feyrer, S. Fong, K. Gehrts, L. Grimaldo, B. Herbold, P. Hrodey, A. Mueller-Solger, T. Sommer, and K. Souza. 2010. Interagency Ecological Program 2010 Pelagic Organism Decline Work Plan Synthesis of Results. December 2010. Available at:

http://www.water.ca.gov/iep/docs/FinalPOD2010Workplan12610.pdf

Bay Delta Conservation Plan (BDCP). 2012a. Bay Delta Conservation Plan, Chapter 5, Effects Analysis, Appendix 5.C – Flow, Passage, Salinity, and Turbidity, April 13, 2012. Available at: www.baydeltaconversationplan.com/Library/DocumentsLandingPage/BDCPPlanDocuments.aspx

Bay Delta Conservation Plan (BDCP). 2012b. Bay Delta Conservation Plan, Effects Analysis, February 29, 2012. Available at: www.baydeltaconversationplan.com/Library/DocumentsLandingPage/BDCPPlanDocuments.aspx

Bay Delta Conservation Plan (BDCP). 2012c. Bay Delta Conservation Plan Effects Analysis, -Appendix 5.A.2 – Climate Change Approach and Implications for Aquatic Species, April 30, 2012. Available at: www.baydeltaconversationplan.com/Library/DocumentsLandingPage/BDCPPlanDocuments.aspx

Bay Delta Conservation Plan (BDCP). 2012d BDCP Chapter 3.6 – Conservation Strategy – Adaptive Management and Monitoring Program, February 29, 2012. Available at: www.baydeltaconversationplan.com/Library/DocumentsLandingPage/BDCPPlanDocuments.aspx

Beggel S., I. Werner, R.E. Connon, and J. Geist. 2010. Sublethal toxicity of commercial insecticide formulations and their active ingredients to larval fathead minnow (Pimephales promelas). Science of the Total Environment 408: 3169–3175.

Bennett, W.A., J.A. Hobbs, and S.J. Teh. 2008. Interplay of environmental forcing and growth-selective mortality in the poor year-class success of Delta smelt in 2005. Final Report to Pelagic Organism Decline Management Team, *available* at http://www.science.calwater.ca.gov/pdf/workshops/POD/2008 final/Bennett PODDeltaSmelt2005Report 2008.pdf

Bouley, P. and W. J. Kimmerer. 2006. Ecology of a highly abundant, introduced cyclopoid copepod in a temperate estuary. Marine Ecology Progress Series 324: 219-228.

Brander Susanne M., Werner I., White J.W., Deanovic L.A. 2009. Toxicity of a dissolved pyrethroid mixture to *Hyalella azteca* at environmentally relevant concentrations. Environmental Toxicology and Chemistry: Vol. 28, No. 7 pp. 1493–1499.

Brooks M, Fleishman E, Brown LR, Lehman PW, Werner I, Scholz N, Mitchelmore C, Lovvorn JR, Johnson ML, Schlenk D, van Drunick S, Drever JI, Stoms DM, Parker AE, Dugdale R. 2011. Life histories, salinity zones, and sublethal contributions of contaminants to pelagic fish declines illustrated with a case study of San Francisco Estuary, California, USA. Estuaries and Coasts DOI 10.1007/s12237-011-9459-6.

Brown, L. 2003. Will tidal wetland restoration enhance populations of native fishes? San Francisco Estuary and Watershed Science 1, Issue 1.

Brown, Larry R. and Marissa L. Bauer. 2010. Effects of hydrologic infrastructure on flow regimes of California's Central Valley rivers: Implications for fish populations. River Research and Applications 26:751-765.

Brown, L.R. and D. Michniuk. 2007. Littoral fish assemblages of the alien-dominated Sacramento-San Joaquin delta, California, 1980-1983 and 2001-2003. Estuaries and Coasts 30(1): 186-200.

Brown, T. 2009. Phytoplankton community composition: the rise of the flagellates. IEP Newsletter, Summer/Fall, 22(3): 20-28.

Brown, T. 2010. 2008 Phytoplankton community composition. IEP Newsletter, Spring 2010, 23(2): 9-13.

Brown, T. 2011. Recent phytoplankton trends in the Low Salinity Zone. IEP Newsletter, Spring 2011, 23(2): 10-13.

Brown, T. and K. Hieb. Introduction of the Siberian prawn, *Exopalaemon modestus* (Crustacea: Decapoda: Palaemonidae), to the San Francisco Estuary. Paper in review.

Brown, T., M. Dempsey, J. Evans, A. Hennessy, L. Jones, B. Noble, D. Riordan, M. Vayssières. 2009. Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays During 2007. Annual report to the State Water Resources Control Board.
Brown, T. 2010. 2008 Phytoplankton community composition. IEP Newsletter, Spring 2010, 23(2): 9-13.

Brown, T., M. Dempsey, J. Evans, A. Hennessy, B. Noble, D. Riordan. 2010a. Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays During 2008. Annual report to the State Water Resources Control Board.

Brown, T., M. Dempsey, R. Elkins, H. Fuller, A. Hennessy, B. Noble, D. Riordan. 2010b. Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays During 2009. Annual report to the State Water Resources Control Board.

Brown, T., M. Dempsey, R. Elkins, H. Fuller, A. Hennessy, K. Ho, B. Noble, D. Riordan. 2011. Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays During 2010. Annual report to the State Water Resources Control Board.

California Climate Change Center. 2012. Our Changing Climate 2012: Vulnerability and Adaption to the Changing Climate in California. Summary report on the Third Assessment (CEC).

California Department of Water Resources. (2009). California Water Plan Update 2009. Sacramento, California. http://www.waterplan.water.ca.gov/cwpu2009/index.cfm

Clark, K.W., M.D. Bowen, R.B. Mayfield, K.P. Zehfuss, J.D. Taplin, and C.H. Hanson. 2009. Quantification of pre-screen loss of juvenile steelhead in Clifton Court Forebay. State of California. The California Natural Resources Agency. Department of Water Resources. Fishery Improvements Section Bay-Delta Office. 119 pp.

California Department of Fish and Game. 2009. A status review of longfin smelt (*Spirinchus thaleicthys*) in California. Report to the Fish and Game Commission, January 23, 2009.

California Department of Water Resources. 2006. California Central Valley Unimpaired Flow Data, Fourth Edition, Bay-Delta Office, California Department of Water Resources, Sacramento, CA.

Chen, Wei-Hsiang, Kristine Haunschild, Jay R. Lund, William E Fleenor. 2010. Current and Long-Term Effects of Delta Water Quality on Drinking Water Treatment Costs from Disinfection Byproduct Formation. San Francisco Estuary and Watershed Science, 8(3).

Cloern, J.E. and A.D. Jassby. 2008. Complex seasonal patterns of primary producers at the land-sea interface. Ecology Letters 11:1-10.

Cloern, J.E. K.A. Hieb, T. Jacobson, B. Sansó, E. Di Lorenzo, M.T. Stacey, J.L. Largier, W. Meiring, W.T. Peterson, T.M. Powell, M. Winder, and A.D. Jassby. 2010. Biological communities in San Francisco Bay track large-scale climate forcing over the North Pacific. Geophysical Research Letters 37:L21602.

Cloern JE, Knowles N, Brown LR, Cayan D, Dettinger MD, Morgan TL, Schoellhamer DH, Stacey MT, van der Wegen M, Wagner RW, Jassby AD. 2011 Projected Evolution of California's San Francisco Bay-Delta-River System in a Century of Climate Change. PLoS ONE 6(9): e24465. doi:10.1371/journal.pone.0024465

Cohen, A. N., and J. T. Carlton. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279:555-558.

Connon R.E., Beggel S., D’Abronzo L.S., Geist J., Loguinov A.S., Vulpe C.D., Werner I. 2010. Linking molecular biomarkers with higher level condition indicators to identify effects of copper exposures on the endangered delta smelt (Hypomesus transpacificus). Environmental Toxicology and Chemistry. In press.

Connon, Richard, Linda Deanovic, Inge Werner. 2010. Application of novel biomarkers to determine sublethal contaminant exposure and effects in delta smelt. Poster presented at Interagency Ecological Program 2010 Annual Workshop. Sacramento, CA, May 26, 2010.

Connon RE, Deanovic LA, Fritsch EB, D'Abronzo LS, Werner I.(2011) Sublethal responses to ammonia exposure in the endangered delta smelt; Hypomesus transpacificus (Fam. Osmeridae). Aquatic Toxicology. 2011 Oct; 105 (3-4):369-77. Epub 2011 Jul 8.

Crain, P.K. and P.B. Moyle. 2011. Biology, history, status and conservation of Sacramento perch, *Archoplites interruptus*. San Francisco Estuary and Watershed Science 9(1): http://escholarship.org/uc/item/8st5g6df

Dege, M. and L.R. Brown. 2004. Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. Pages 49–66 in F. Feyrer, L.R. Brown, R.L. Brown, and J.J. Orsi, editors. Early life history of fishes in the San Francisco Estuary and watershed. American Fisheries Society Symposium 39.

Deng, D., K. Zheng, F. Teh, P. W. Lehman, S. J. Teh. 2010. Toxic Threshold of Dietary Microcystin (-LR) for Quart Medaka. Toxicon 55: 787794.

Department of Boating and Waterways. 2009. Egeria densa control program annual report.

Dettinger, M.D. 2005. From climate-change spaghetti to climate-change distributions for 21st Century California. San Francisco Estuary and Watershed Science Vol. 3 Issue 1 Article 4. http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art4.

Dettinger, M.D. 2011. Climate change, atmospheric rivers, and floods in California – A multimodel analysis if storm frequency and magnitude changes. Journal of the American Water Resources Association. 47(3): 514-523.

Dugdale, R.C., F.P. Wilkerson, V.E. Hogue, and A. Marchi. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science 73(1-2):17-29.

Enright C, Culberson SD. 2010. Salinity trends, variability, and control in the northern reach of the San Francisco Estuary. San Francisco Estuary and Watershed Science, 7(2). Retrieved from: http://escholarship.org/uc/item/0d52737t

Feyrer, F., B. Herbold, S.A. Matern, and P.B. Moyle. 2003. Dietary shifts in a stressed fish assemblage: Consequences of a bivalve invasion in the San Francisco Estuary. Environmental Biology of Fishes 67:277–288.

Feyrer, F., M. Nobriga, and T. Sommer. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734.

Feyrer, F., T. Sommer and S. Slater. 2009. Old School vs. New School: Status of Threadfin Shad Five Decades after its Introduction to the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science. Vol. 7, Issue 1, Article 3.

Feyrer, F., M. Nobriga, T. Sommer, and K. Newman. 2010. Modeling the effects of future freshwater flow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts. Published online 28 September 2010, DOI 10.1007/s12237-010-9343.

Fleenor, William E, Ellen Hanak, Jay R. Lund, Jeffrey R. Mount. 2008. Technical Appendix C: Delta Hydrodynamics and Water Salinity with Future Conditions. Prepared as an appendix to: Comparing Futures for the Sacramento-San Joaquin Delta, Public Policy Institute of California.

Foe, C., A. Ballard, and S. Fong, 2010. Nutrient Concentrations and Biological Effects in the Sacramento-San Joaquin Delta, Regional Board report, 87p.

Fuller, H. 2012. Benthic monitoring, 2011. IEP Newsletter, in press.

Fuller, H. 2011. Benthic monitoring, 2010. IEP Newsletter, Spring 2011, 24(2): 13-19.

Ger, K. A., S. J. Teh, and C. R. Goldman. (2009). "Microcystin-LR toxicity on dominant copepods *Eurytemora affinis* and *Pseudodiaptomus forbesi* of the upper San Francisco Estuary." Science of the Total Environment 407(17): 4852-4857. DOI: 10.1016/j.scitotenv.2009.05.043

Ger, Kemal A. Swee J. Teh, Dolores V. Baxa, Sarah Lesmeister, and Charles R. Goldman. 2010a. The effects of dietary Microcystis aeruginosa and microcystin on the copepods of the upper San Francisco Estuary. Freshwater Biology - Published Online: 4 Feb 2010.

Ger, Kemal Ali, Patty Arneson, Charles R. Goldman, Swee J. Teh. 2010b. Species specific differences in the ingestion of Microcystis cells by the calanoid copepods Eurytemora affinis and Pseudodiaptomus forbesi. Journal of Plankton Research Advance Access published on June 18, 2010.

Glibert PM. 2010. Long-term changes in nutrient loading and stoichiometry and their relationships with changes in the food web and dominant pelagic fish species in the San Francisco Estuary, California. Reviews in Fisheries Science 18:211–232.

Glibert PM, Fullerton D, Burkholder JM, Cornwell JC, Kana TM. 2011.Ecological Stoichiometry, Biogeochemical cycling, invasive species, and aquatic food webs: San Francisco Estuary and Comparative Systems. Reviews in Fisheries Science 19:4:358-417

Gould, A.L. and W.J. Kimmerer. 2010. Development, growth, and reproduction of the cyclopoid copepod Limnoithona tetraspina in the upper San Francisco Estuary. Marine Ecology Progress Series 412: 163-177.

Grimaldo, L.F, R.E. Miller, C.M. Peregrin, and Z.P Hymanson. 2004. Spatial and temporal distribution of ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. Pages 81-96 in F. Feyrer, L.R. Brown, R.L. Brown, and J.J. Orsi, editors. Early Life History of Fishes in the San Francisco Estuary and Watershed. American Fisheries Society, Symposium 39, Bethesda, Maryland.

Grimaldo, L.F., A.R. Stewart, W. Kimmerer. 2009a. Dietary segregation of pelagic and littoral fish assemblages in a highly modified tidal freshwater estuary. Marine Coastal Fisheries: Dynamics, Management & Ecosystems Sciences. 1: 200–217.

Grimaldo, L.F., T. Sommer, N. Van Ark, G. Jones, E. Holland, P.B. Moyle, B. Herbold, P.Smith.2009b. Factors affecting fish entrainment into massive water diversions in a tidal freshwater estuary: Can fish losses be managed? North American Journal of Fisheries Management 29: 1253-1270

Hestir, Erin L. 2010. Trends in estuarine water quality and submerged aquatic vegetation. PhD thesis. University of California, Davis.

Hobbs. James A, Levi S. Lewis., Naoaki Ikemiyagi., Ted Sommer and Randall D. Baxter. 2010. The use of otolith strontium isotopes (87Sr/86Sr) to identify nursery habitat for a threatened estuarine fish. Environ Biol Fish (2010) 89:557–569.

Hollibaugh, J.T., and P.S. Wong. 1996. Distribution and activity of bacterioplankton in San Francisco Bay. Pages 263–288 in J. T. Hollibaugh, editor. San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science, San Francisco, CA.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability–Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (eds). Cambridge University Press. New York, NY.

Jassby, A. 2008. Phytoplankton in the Upper San Francisco Estuary: Recent biomass trends, their causes and their trophic significance. San Francisco Estuary and Watershed Science 6(1): Article 2.

Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel FR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5:272-289.

Jassby AD, Cloern JE, Cole BE. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnology and Oceanography 47: 698-712.

Khan and Schwarz. 2010 . Climate Change Characterization and Analysis in California Water Resources Planning Studies. http://www.water.ca.gov/climatechange/docs/DWR_CCCStudy_FinalReport_Dec23.pdf

Kimmerer WJ. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages. Marine Ecology Progress Series 243:39-55.

Kimmerer, W.J. 2008. Losses of Sacramento river Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 6(2): http://escholarship.org/uc/item/7v92h6fs

Kimmerer, W.J., E. Gartside, J.J. Orsi. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. Marine Ecology Progress Series 113: 81–93.

Kimmerer, W. J., and J. J. Orsi. 1996. Changes in the zooplankton of the San Francisco Bay Estuary since the introduction of the clam Potamocorbula amurensis. Pages 403-424. in J.T.

Hollibaugh, ed. San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science. San Francisco, California.

Kimmerer, W.J., E.S. Gross, and M.L. MacWilliams. 2009. Is the Response of Estuarine Nekton to Freshwater Flow in the San Francisco Estuary Explained by Variation in Habitat Volume? Estuaries and Coasts 32:375-389.

Knowles N. 2010. Potential inundation due to rising sea levels in the San Francisco Bay Region. San Francisco Estuary and Watershed Science. Vol. 8, Issue 1. Retrieved from: http://escholarship.org/uc/item/8ck5h3qn

Knowles, N. and D. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. Geophysical Research Letters 29:38-1–38-4.

Knowles, N. and D. Cayan. 2004. Elevational dependence of projected hydrologic changes in the San Francisco Estuary and watershed. Journal Climatic Change 62:319–336.

Kuivila K, Moon GE. 2004. Potential exposure of larval and juvenile delta smelt to dissolved pesticides in the Sacramento–San Joaquin Delta, California. In: Feyrer F, Brown LR, Brown RL, Orsi JJ, editors. Early Life History of Fishes in the San Francisco Estuary and Watershed. Bethesda (MD). American Fisheries Society Symposium 39: p. 229–241.

Kugrens P, Clay BL. 2003. Cryptomonads. In: Wehr JD, Sheath, RG, editors. Freshwater Algae of North America: Ecology and Classification. Academic Press, p. 715-755.

Lehman, P.W. 1998. Phytoplankton species composition, size structure, and biomass and their possible effect on copepod food availability in the low salinity zone of the San Francisco. IEP technical report No 62. August 1998.

Lehman, P.W. 2000a. The influence of climate on phytoplankton community biomass in San Francisco Bay Estuary. Limnology and Oceanography 45(3):580-590.

Lehman, P.W. 2000b. Phytoplankton biomass, cell diameter, and species composition in the low salinity zone of the northern San Francisco Bay Estuary. Estuaries 23(2):216-230.Lehman, P. W., and R. W. Smith. 1991. Environmental factors associated with phytoplankton succession for the Sacramento-San Joaquin Delta and Suisun Bay Estuary, California. Estuarine, Coastal and Shelf Science 32:105-128.

Lehman, P. W., and R. W. Smith. 1991. Environmental factors associated with phytoplankton succession for the Sacramento-San Joaquin Delta and Suisun Bay Estuary, California. Estuarine, Coastal and Shelf Science 32:105-128.

Lehman, P. W., G. Boyer, C. Hall, S. Waller, K. Gehrts. 2005. Distribution and toxicity of a new colonial *Microcystis aeruginosa* bloom in the San Francisco Bay Estuary, California. Hydrobiologia 541: 87-99.

Lehman, P. W., T. Sommer & L. Rivard, 2008. The influence of floodplain habitat on the quantity of riverine phytoplankton carbon produced during the flood season in San Francisco Estuary. Aquatic Ecology 42: 363-378.

Lehman, P. W., S. Mayr, L. Mecum and C. Enright. 2010b. The freshwater tidal wetland Liberty Island, CA was both a source and sink of inorganic and organic material to the San Francisco Estuary. Aquatic Ecology 44:359–372.

Lehman, P. W., S. Teh, G. L. Boyer, M. Nobriga, E. Bass and C. Hogle. 2010a. Initial impacts of Microcystis on the aquatic food web in the San Francisco Estuary. Hydrobiologia 637: 229-248.

Loboschefsky, Erik; Benigno, Gina; Sommer, Ted; Rose, Kenneth; Ginn, Timothy; Massoudieh, Arash; et al.(2012). Individual-level and Population-level Historical Prey Demand of San Francisco Estuary Striped Bass Using a Bioenergetics Model. San Francisco Estuary and Watershed Science, 10(1). jmie_sfews_11153. Retrieved from: http://escholarship.org/uc/item/1c788451

Lund J, Hanak E, Fleenor W, Howitt R, Mount J, Moyle P. 2007. Envisioning futures for the Sacramento–San Joaquin Delta. Public Policy Institute of California.

Lund, J., E. Hanak, W. Fleenor, W. Bennett, R. Howitt, J. Mount, and P. Moyle. 2008. Comparing Futures for the Sacramento-San Joaquin Delta. Public Policy Institute of California.

Mac Nally, Ralph, James R. Thomson, Wim J. Kimmerer, Frederick Feyrer, Ken B. Newman, Andy Sih, William A. Bennett, Larry Brown, Erica Fleishman, Steven D. Culberson, and Gonzalo Castillo. 2010. An analysis of pelagic species decline in the upper San Francisco Estuary using Multivariate Autoregressive modeling (MAR). Ecological Applications, 20: 167-180.

Matern, S.A., P.B. Moyle and L.C. Pierce. 2002. Native and Alien Fishes in a California Estuarine Marsh: Twenty-One Years of Changing Assemblages Transactions of the American Fisheries Society 131:797–816.

Mittelbach, G. G., A.M. Turner, D.J. Hall, J.E. Rettig, and C. W. Osenberg. 1995. Perturbation and resilience: a long-term, whole-lake study of predator extinction and reintroduction. Ecology 76: 2347-2360.

Moisander, P. H., P. W.Lehman, M. Ochiai and S. Corum. 2009. Diversity of the toxic cyanobacterium *Microcystis aeruginosa* in the Klamath River and San Francisco Bay delta, California. Aquatic Microbial Ecology 57: 19–31.

Moyle, Peter B. 2002. *Inland Fishes of California.*University of California Press. Berkeley, California.

National Research Council. Sustainable Water and Environmental Management in the California Bay-Delta . Washington, DC: The National Academies Press, 2012a. Available at: http://dels.nas.edu/Report/Sustainable-Water-Environment/13394

National Research Council. 2012b. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. July.

Nichols, F.H., J.E. Cloern, S.N. Luoma, and D.H. Peterson. 1986. The modification of an 5312 estuary. Science 231:567–573.

Nobriga, M.L. 2009. Bioenergetic modeling evidence for a context-dependent role of food limitation in California's Sacramento-San Joaquin delta. California Fish and Game 95(3): 111-121.

Nobriga, Matthew L. and Frederick Feyrer. 2007. Shallow-water piscivor-prey dynamics in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science Vol 5, Issue 2. Article 4.

Nobriga M.L., F. Feyrer, R.D. Baxter, and M. Chotkowski. 2005. Fish community ecology in an altered river delta: spatial patterns in species composition, life history strategies, and biomass. Estuaries 28(5): 776-785.

Nobriga, M., T. Sommer, F. Feyrer, and K. Fleming. 2008. Long-term trends in summertime habitat suitability for delta smelt, Hypomesus transpacificus. San Francisco Estuary and Watershed Science.

Orsi, J.J. and W.L. Mecum. 1996. Food limitation as the probable cause of a long-term decline in the abundance of Neomysis mercedis the opossum shrimp in the Sacramento-San Joaquin estuary. Pages 375–401 in J.T. Hollibaugh, editor. San Francisco Bay: the ecosystem. American Association for the Advancement of Science. San Francisco, CA.

Peterson, Heather A, and Marc Vayssieres. 2010. Benthic Assemblage Variability in the Upper San Francisco Estuary: A 27-Year Retrospective. San Francisco Estuary and Watershed Science, 8(1).

Parker, A.E., A.M. Marchi, J.Drexel-Davidson, R.C. Dugdale, and F.P. Wilkerson. 2010a. “Effect of ammonium and wastewater effluent on riverine phytoplankton in the Sacramento River, CA. Draft Final Report. March 17, 2010.

Parker, A.E., R. C. Dugdale, F.P.Wilkerson, A. Marchi, 2010b. “Biochemical Processing of Anthropogenic Ammonium in the Sacramento River and northern San Francisco Estuary: Consequences for Pelagic Organism Decline. Presented at the 6th Biennial Bay-Delta Science Conference held in Sacramento California on 27-29 September 2010.

Pfeffer, W. T., J. T. Harper, and S. O’Neel. 2008. Kinematic constraints on glacier contributions to 21st century sea-level rise. Science 321:1340–134. As referenced in National Research Council 2012.

Rahmstorf, Stefan. 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. Science 19 January 2007: Vol. 315 no. 5810 pp. 368-370.

Rosenfield J.A. and R.D. Baxter. 2007. Population dynamics and distribution patterns of longfin smelt in the San Francisco Estuary. *Transactions of the American Fisheries Society 136:1577-1592.*

Santos, Maria J., Lars W. Anderson, Susan L. Ustin. 2011. Effects of invasive species on plant communities: an example using submersed aquatic plants at the regional scale. Biological Invasions 13: 443-457.

Santos, Maria J., Erin L. Hestir, Shruti Khanna, and Susan L. Ustin. 2012. Image spectroscopy and stable isotopes elucidate functional dissimilarity between native and nonnative plant species in the aquatic environment. New Phytologist:. 139: 683-695.Santos et al. 2011.

Schemel, L.E., T.R. Sommer, A.B. Mueller-Solger, and W.C. Harrell. 2004. Hydrologic variability, water chemistry and phytoplankton biomass in a large floodplain of the Sacramento Rive, CA, USA. Hydrobiologia 513:129-139

Schoellhamer DH. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34(5):885-899

Schroeter, R. 2008. Biology and long-term trends of alien hydromedusae and striped bass in a brackish tidal marsh in the San Francisco Estuary. PhD Dissertation. UC Davis.

Slaughter, A. and W . Kimmerer. 2010. Abundance, composition, feeding, and reproductive rates of key copepod species in the food-limited Low Salinity Zone of the San Francisco Estuary.

Poster Presentation at the 6th Biennial Bay-Delta Science Conference, Sacramento, CA, September 27-29, 2010.

Sobczak, W.V., J.E. Cloern, A.D. Jassby, and A.B. Muller-Solger. 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proceedings of the National Academy of Sciences 99:8101–8105. 544

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32:270-277.

Sommer, T.R., W.C. Harrell, A. Mueller-Solger, B. Tom, and W. Kimmerer. 2004. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 14:247-261

Sommer, T., F, Mejia, M. Nobriga, F. Feyrer, and L. Grimaldo. 2011a. The Spawning Migration of Delta Smelt in the Upper San Francisco Estuary. San Francisco Estuary and Watershed Science (2011) 9 (2), 16 pages.

Sommer, T., F. Mejia, K. Hieb, R. Baxter, E. J. Loboschefsky and F. J. Loge. 2011b. Long-term shifts in the lateral distribution of age-0 striped bass Morone saxatilis in the San Francisco estuary. Transactions of the American Fisheries Society 140: 1451-1459.

Sommer, T. and F. Mejia. In Review. A place to call home: A synthesis of delta smelt habitat in the upper San Francisco Estuary. Submitted to San Francisco Estuary and Watershed Science.

Stewart, A.R., S.N. Luoma, C.E. Schlekat, M.A. Doblin, and K.A. Hieb. 2004. Food web pathway determines how selenium affects aquatic ecosystems: A San Francisco Bay case study. Environmental Science and Technology 38:4519–4526.

Swanson, C., T. Reid, P.S. Young, and J.J. Cech, Jr. 2000. Comparative environmental tolerances of threatened delta smelt (Hypomesus transpacificus) and introduced wakasagi (H. nipponensis) in an altered California estuary. Oecologia 123:384–390.

Teh, S.J., Lu, M., Teh, F.C., Lesmeister, S., Werner, I., Krause, J., Deanovic, L. 2008. Toxic effects of surface water in the upper San Francisco Estuary on Eurytemora affinis. San Luis and Delta-Mendota Water Authority. Final Report.

Teh, S., I. Flores, M. Kawaguchi, S.Lesmeister, and C. Teh. 2011. Full life-cycle bioassay approach to assess chronic exposure of Pseudodiaptomus forbesi to ammonia/ammonium. Submitted to: C. Foe and M. Gowdy State Water Board / UC Davis Agreement No. 06-447-300, SUBTASK No. 14, (March 4, 2011).

Thomson, J.R., W. J. Kimmerer, L. R. Brown, K. B. Newman, R. Mac Nally, W. A. Bennett, F. Feyrer, E. Fleishman. 2010. Bayesian change-point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications, 20: 181-198.

U.S. Bureau of Reclamation. 2012. Draft 2012 Plan for Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability. http://deltacouncil.ca.gov/sites/default/files/documents/files/Revised_Fall_X2_Adaptive_MgmtPlan_EVN_06_29_2012_final.pdf

USFWS (United States Fish and Wildlife Service). 2008. Formal Endangered Species Act consultation on the proposed coordinated operations of the Central Valley Project (CVP) and State Water Project (SWP).

Vermeer, M. and S. Rahmstorf. 2009. Global sea level linked to global temperature. Proceedings of the National Academy of Sciences, Vol. 106, No. 51. (22 December 2009), pp. 21527-21532. As referenced in National Research Council 2012.

Wagner R, Stacey MT, Brown L, Dettinger M. 2011. Statistical models of temperature in the Sacramento-San Joaquin Delta under climate-change scenarios and ecological implications. Estuaries and Coasts 34: 544–556.

Wang J, Yin H, Chung F. 2011. Isolated and integrated effects of sea level rise, seasonal runoff shifts, and annual runoff volume on California's largest water supply. Journal of Hydrology. May, 2011.

Werner, I. and J.T. Hollibaugh. 1993. Potamocorbula amurensis: comparison of clearance rates and assimilation efficiencies for phytoplankton and bacterioplankton. Limnology and Oceanography 38:949–964.

Werner, I., L.A. Deanovic, M. Stillway, and D. Markiewicz. 2009. “Acute toxicity of ammonia/um and wastewater Treatment effluent-associated contaminants on Delta smelt. Final Report. April 3, 2009.

Werner, I., L.A. Deanovic, D. Markiewicz, J. Khamphanh, C.K. Reece, M. Stillway, C. Reece. 2010. Monitoring acute and chronic water column toxicity in the northern Sacramento-San Joaquin Estuary, California, USA, using the euryhaline amphipod, Hyalella azteca: 2006-2007. Environmental Toxicology and Chemistry 29(10): 2190–2199.

Weston D. P. and M. J. Lydy. 2010. Urban and Agricultural Sources of Pyrethroid Insecticides to the Sacramento-San Joaquin Delta of California. Environ. Sci. Technol. 44 (5): 1833–1840.

Wilkerson FP, Dugdale RC, Hogue VE, Marchi A. 2006. Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts 29:401–416.

Winder, Monika, and Alan D. Jassby. 2010. Zooplankton dynamics in the upper San Francisco Estuary: Long-term trends and food web implications. Estuaries and Coasts DOI: 10.1007/s12237-010-9342-x.

Wright SA, Schoellhamer DH. 2004. Trends in the sediment yield of the Sacramento River, California, 1957-2001. San Francisco Estuary and Watershed Science 2. Available:

http://repositories/cdlib.org/jmie/sfews/vol2/iss2/art2