LATE COMMENT

Bay-Delta Workshop #2: Review scientific and technical basis for considering potential changes to 2006 Bay-Delta Plan.

The Independent Science Panel on Bay-Delta Fishery Resources developed this memo as a synthesis of present knowledge and to offer a common view of key scientific considerations in revision of the Bay-Delta Plan. This memo is intended as a basis for discussion at the State Water Resources Control Board (SWRCB) workshop scheduled to address Bay-Delta Fishery Resources on 1-2 October 2012. The memo was compiled during August and September 2012.

Three themes are addressed:

- *Implications of science for management* – Management of the Bay-Delta system can be improved in the context of fishery resources. Current scientific understanding leads to specific suggestions for improved management, which are noted here.
- *Need for improved science to reduce uncertainty* – Uncertainty in the expected outcome of policy choices and management options can be reduced through strategic investment in improved scientific knowledge. Specific suggestions are made here.
- *Key emerging science* – Scientific knowledge has continued to increase since the 2006 Bay-Delta Plan, better informing management. Key new ideas are highlighted here, and should be considered in a forward-looking plan.

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1. Implications of Science for Management

1.1. Develop new water quality objectives that account for simultaneous effects on multiple species, correlations between criteria, and non-linear responses of fishery resources to criteria.

Consider how to combine existing and proposed new water quality criteria across species to address possible interactions and conflicts. Existing criteria include Delta outflow, export limits (E/I ratio), DCC operations, Old and Middle River flows, X2 objectives, salinity requirements, floodplain-habitat flow objectives, and Suisun Marsh objectives. The current approach appears to be to simply overlay the criteria for each species on top of each other and select the most limiting criteria. Interaction between species means that a criterion affects more than one species of interest. Therefore, there are the possibilities of synergistic effects and unintended negative consequences from water quality objectives that should be considered.

Secondly, diverse water quality criteria are interrelated. Specifically, Delta flow objectives affect tributaries below dams and Bay conditions in addition to those in the Delta – e.g., management of X2 affects flow in the Sacramento and San Joaquin basins and the amount of cold water in SWP and CVP reservoirs, which are important for temperature management in upstream salmonid habitats.

Also, relationships between fish benefits (e.g., abundance, growth) and water objectives are often not linear. For example, a doubling of a flow objective often does not result in a doubling of the benefit; and a certain percent increase in flow at two different flow levels does not result in the same percentage benefit. Nonlinear dependence on water quality variables (e.g., flow, X2) should be explicitly considered across species as new water quality objectives are developed.

1.2. Monitor effectiveness of management actions with respect to ecosystem and fish goals.

Assessment of the utility of water quality objectives should, in some critical cases, go beyond compliance monitoring and include monitoring of biological and fish benefits. Compliance monitoring is how well the objective was met (e.g., salinity at certain locations). Effectiveness monitoring would assess whether the expected or anticipated biological responses associated with achieving the water quality objective were also being obtained. Examples of effectiveness monitoring variables would be fish condition, growth rates, and spatial distributions. The tools needed for effectiveness monitoring include biological sampling, modeling, and a strategy for analyzing the data and designing model simulations. Confirmation that the assumed biological benefits of water quality objectives, often used to justify the objectives, will be needed and will require additional monitoring and modeling beyond determination of compliance.

The specification of expected biological and fish benefits will also move the Board to avoid using the generic term “habitat”. There is a need to be specific about what is meant by habitat benefits (e.g., fish growth, survival, or reproduction) and why it is important. In all cases, a specific benefit is being anticipated, and this should be stated. General reference to habitat allows each person to anticipate a different specific benefit, which leads to miscommunication and conflict in expectations.

1.3. Develop a strategy for assessing water quality under future system configurations.

In anticipation of the possibility of a dual conveyance facility, other major infrastructure changes related to BDCP, other planning activities (e.g., changes to reservoirs, groundwater storage), and climate change, develop a strategy to assess the justification and feasibility of water quality standards under future scenarios. These future scenarios involve system configurations that do not yet exist. An appropriate strategy (e.g., data needed, how analyzed, etc.) will define the information that needs to be collected so the Board is properly prepared for future evaluations of water quality objectives.

1.4. Assess the use of summary indicators for specific purposes.

Summary measures of hydrological conditions are valuable – often providing effective indices of aggregate state of the system. However, summary measures, such as outflow or the ratio of inflows to exports (I/E) are not always sufficiently sensitive to how water is routed through the system and measures aggregated over long periods do not reflect flow variability on shorter time scales. Such flow variability in space and time can be important to fish (e.g., migration cues, vulnerability to entrainment), and varies among species. For example, summary measures that include inflow:export ratio (I/E), export :inflow ratio (E/I), Old and Middle River flows (OMR; a function of San Joaquin River inflow and exports), and Delta Outflow (Delta inflow minus exports and in-Delta use) do not index in any detail how, where, and to what extent river inflows and exports are influencing the fish species of concern. Specifically, the use of an I/E ratio implies that decrease in exports is equivalent to increase in river inflows, but studies to date have not supported this conclusion. While quantitative analyses from mark-recapture experiments and correlative analysis of spawning escapements in the San Joaquin portion of the Delta have been inconclusive regarding the adverse effect of exports on the survival of juvenile salmonids (Baker and Morhardt 2001; CDFG 2005; SJRGA 2007; Mesick and Marston 2007; Newman 2008a), several studies have found evidence for a positive effect of San Joaquin River inflows on survival of juvenile salmonids emigrating through the lower river and Delta (CDFG 2005; Newman 2008a). Because flow patterns and variability can affect fish differently, the usefulness of summary measures needs to be demonstrated before being used as an index for specific fish benefits.

1.5. Proceed with management based on existing data and models.

New analyses of data and development of new hydrodynamic and fish-related models for the Bay-Delta system will be ongoing. Rather than waiting for the promise of the next version of analyses or the next generation of models (in the hope that the next analysis or model will be a "break-through"), we urge the Board to proceed with revising water quality objectives based on tools that are available now or truly imminent. Specifically, it is not clear how much improvement in accuracy and precision will be provided by new 2-dimensional and 3-dimensional hydrodynamic models. There are many existing biological data analyses and biological simulation models that are available to help evaluate and understand the expected impact of water management and other stressors on fish populations. These models (including salmon and delta smelt models) should be used to their full potential. However, the Panel only recommends the use of models that are well documented, transparent, and readily available, with clearly stated and well justified assumptions. The Panel also recognizes that further model development is important, specifically in effective coupling of biological models with hydrodynamic models, which typically use different spatial grids and time steps. We encourage the Board to take advantage of new models as they become available and gain support from the science community.

1.6. Outline the beneficial uses of water flow in terms of water quality objectives.

Given the intensity of debate among stakeholders, it is important to identify and clearly state how water flow rates affect water quality objectives and which beneficial uses are being addressed. With historical focus on fish issues, the degree of consideration provided to other beneficial uses is not always clear to stakeholders. The Panel is not commenting on the process taken by the Board in developing the objectives, but rather just offering a reminder for extra effort on specificity and communication. This is especially important when it comes to evaluating the impacts of proposed water quality objectives and alternatives on other uses of the water (e.g., water supply, diversions) and ecological benefits of the water on other than the listed fish species (e.g., LSZ or Suisun Marsh).

1.7. Consider the short-term variability of water quality parameters.

Water quality objectives are often based on aggregate values of variables (e.g., mean monthly outflow at a location) and do not consider the shorter-scale temporal variability of these variables. The same average value can be obtained with different levels of shorter-scale variability (e.g., daily changes relative to monthly mean), and the degree of variability, in addition to the average value, can be very important to the fish responses. Others have discussed this in more detail (see Moyle et al. 2010). The importance of environmental variability to specific fish needs to be assessed and included in water quality objectives where appropriate.

1.8. Consider contaminants and other stressors together with flow.

While separating the effects of flow from many other stressors (e.g., contaminants, nutrients) is practical and enables a more tractable modular approach to developing the water quality standards, flow is not independent of these other stressors. We recommend that water quality objectives be developed based on a holistic view of stressors, including potential interactions among stressors. In this context of multiple stressors, it is important to articulate clearly how policy is optimal in terms of benefits versus costs.

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2. Need for improved science to reduce uncertainty

2.1. Need for models that can assess benefits of Bay-Delta Plan for specific species on sufficiently fine time and space scales.

New modeling should account for flow from dams through Delta to estuary, and be capable of identifying the flow needs of fish on multiple space and time scales. Models are needed for individual species (e.g., Chinook salmon, delta smelt, longfin smelt) and for fish communities (e.g., pelagic fishes). Model aims include: (i) quantify fish-based benefits of water quality objectives, (ii) identify unintended consequences of objectives, and (iii) evaluate cost-benefit trade-offs among objectives across life stages and species. Current and future municipal, agricultural, and environmental needs for limited water resources will demand this level of specific accounting. Specific and demonstrated fisheries benefits will be needed to make informed and effective decisions about renewing/refining/developing water quality objectives. Specific flow conditions are needed for some species year-round (e.g., tributaries for steelhead) and for other species in certain seasons (e.g., winter and spring for longfin smelt). Moreover, migratory species have flow requirements along their migration routes throughout the system.

For example, a winter-run Chinook life-cycle model, which includes routing, inflow and export effects within the Delta is now available (Zeug et al. 2012) and actively in use for evaluating and planning projects like the Bay Delta Conservation Plan. A model in development for delta smelt population dynamics (Newman et al. 2012) will account for flows and a variety of other important variables within its range (Delta and Suisun Bay/Marsh). The Newman et al. (2012) model will be a quantitative life-cycle model that (i) includes space explicitly, (ii) uses data input from individual fish surveys, thus retaining small space and time information, (iii) resolves individual population processes (e.g., survival, reproduction, movement), and (iv) has been developed to provide assessments and projections for management actions. Other models for delta smelt have also recently been developed (e.g., Maunder and Deriso 2011).

2.2. Need for experimental evaluation of flow-related management actions.

Much of our knowledge of factors that drive fish abundance in the Delta system has been derived from correlative analyses of long-term data sets, except in the case of salmonids for which a large volume of mark-recapture data is available. A wide range of mechanisms and underlying processes has been postulated to explain observed relationships (e.g., Stevens and Miller 1983, Kimmerer 2002). Although these relationships hold up, to varying degrees, under scrutiny and as more data are added, there remains a lack of understanding of the specific mechanisms underlying these relationships. Flow-related management actions should be experimentally evaluated to (i) confirm that they generate the expected benefits, (ii) to gain a better mechanistic understanding of the processes involved, (iii) to reduce uncertainty in assessment of benefits, and (iv) to refine water-quality objectives. Flow-related management actions can be used as experiments. These experiments should include extremes within the water project operational range. For example, since 1995 juvenile salmonid mark-recapture studies have focused almost exclusively on minimum export conditions (see Newman 2008a) – a high-export, high-river-inflow experiment might yield important insights for balancing water supply and fish needs. Effective use of such experiments requires development of conceptual models and analysis of existing data and numerical models to identify possible modes of action and anticipated outcomes. Observations of flow at smaller scales, fish response variables, and important covariates must be collected during the experiment. The ability to make a precise prediction, followed by accurate assessment of outcomes (e.g., measurements), is critical to effective experimentation. Repeated success in using an experimental approach (prediction and outcome) reduces uncertainties and increases our confidence in implementation of the water quality objectives.

The Fall Low Salinity Habitat (USBR 2012) investigation to examine potential effects of flow management during fall (FLaSH) provides an example of this process. In an initial phase, specific goals and objectives are described, conceptual models are developed, specific predictions of the response of the ecosystem to flow changes are articulated, and a science plan is developed. The science plan guides the subsequent monitoring and focused research studies as well as how the predictions are evaluated. Further, the FLaSH project includes an iterative component that incorporates input from different groups in establishing alternatives, and that includes peer review of the plan and results. Another example of a study that used a structured experimental evaluation of factors influencing juvenile salmon survival during emigration through the lower Mokelumne River is provided by Cavallo et al. (2012), who looked at both flow and predation factors.

2.3. Need to link ocean variability to variability in Bay-Delta habitats and in fish species abundances.

Recently it has become clear that external forcing from the ocean end of the estuary is an important factor in species abundances in the Bay-Delta system. Specifically, Cloern et al. (2010) show that ocean conditions correlate with marked changes in populations in the system: the abundance of a suite of demersal marine fishes (5 species), crabs (3 species), and shrimp (2 species) in the lower estuary co-varied with large-scale interannual changes in the eastern Pacific, as indexed by the Pacific Decadal Oscillation and the North Pacific Gyre Oscillation. A major shift in ocean conditions, which occurred after 1999, accounted for previously unexplained, large increases in abundance of these species. Ocean cooling, increased productivity, and increased nearshore retention associated with this climate shift (Cloern et al. 2010), along with increased productivity in the lower estuary (Cloern et al. 2007), likely benefited these species and may also have provided benefits to anadromous species passing through or rearing in the region (e.g., longfin smelt, Chinook salmon, steelhead, striped bass and American shad). Another example of the role of ocean conditions is the marine survival of salmon, which can have a large effect on population dynamics relative to water management actions within the system (Lindley et al. 2009).

More generally, the Bay-Delta environment fluctuates in response to forcing from watershed, ocean and atmosphere, which vary with the seasons and interannually. The ocean influence occurs through intrusion of seawater into the Bay as well as through migration or dispersal of selected planktonic life stages between the ocean and Bay. Seawater intrudes into the Bay-Delta system as far as non-zero salinity is recorded, often indexed by X2 (the position of the 2 ppt salinity contour – Monismith et al. 2002), and the interaction of these dense waters with outflowing freshwater drives the gravitational circulation (landward-enhanced flow near-bottom and seaward-enhanced flow near-surface). This gravitational circulation transports nutrients and plankton from the ocean far into the Bay, supporting the productivity of the system – and this gravitational circulation can transport lower-estuary productivity upstream to the low-salinity zone (e.g., marine plankton observed in low-salinity zone during high flows in spring 2006, Kimmerer et al. 2012). Changes in upwelling, circulation, and sea level in the ocean thus propagate into the Bay, with significant influences on environmental conditions and system productivity that are poorly understood. Additional analyses relating ocean conditions and ocean indices to species abundances and within-system conditions would increase our ability to explain population fluctuations and allow for better design of water quality objectives and more accurate isolation of the likely effects of water quality objectives.

2.4. Need to resolve the effect of nutrient types and ratios on Bay-Delta ecosystem processes.

Increased understanding of how nutrient conditions affect the lower food web (phytoplankton and zooplankton) would enable better determination of whether remediation is possible, and ultimately whether such remediation is likely to change the food web sufficiently to contribute to improvements in fish species abundances. Long-term shifts in phytoplankton species composition in the system have been documented (Lehman 2000), and more recently a shift from larger diatoms to smaller flagellates and cynobacteria (Brown 2009; Glibert 2010) has been associated with the increase in ammonium in the Delta from increased loading by wastewater treatment plants (Jassby 2008). This change in the phytoplankton community substantially reduced the food value of phytoplankton to zooplankton (see Lehman 2000, Lehman et al. 2009).

However, the evidence for the link between nutrients and lower trophic levels is stronger than for the next step, from lower trophic levels to fish. To date, we lack evidence of a direct link between changes in nutrient types or ratios and changes in fish abundance, in spite of clear bottom-up effects on fishes (see Baxter et al. 2010). Nevertheless, it is expected that the link between nutrients, lower trophic levels, and fish abundances is important for some life stages, in certain regions of the system, and for certain years. Changes in nutrients, particularly the increasing ammonium concentration, are likely to be one of several important stressors contributing to an apparent regime shift in the system (see Baxter et al. 2010). How the changed linkage will affect lower trophic level responses to water quality objectives remains an important uncertainty that needs to be addressed. Continued investigation of nutrient types and ratios remains warranted (Baxter et al. 2010), although the response of the lower trophic levels to changes in nutrients is often masked in estuaries due to factors like tides, short residence times, turbidity, and top-down (predation) controls.

2.5. Need to refine assessment of the impacts of entrainment on fish populations.

The population-level effect of entrainment resulting from south-Delta water export remains a controversial issue needing additional data and analysis, particularly relating to pelagic fishes. Entrainment is quantified relative to population abundance (i.e., proportional entrainment), but hard data on the number entrained and the number of fish in the population are lacking. Population abundance is not known with sufficient confidence, and data are restricted to when sampling is done. While Newman (2008b) outlines a method to generate estimates of population abundance from monitoring data, there is significant uncertainty as abundance values were sensitive to which surveys were included and how gear selectivity was accounted for. Further, entrainment itself is not directly measured (Grimaldo et al. 2009) – it is often indexed by “salvage”, the number of fish estimated as diverted away from the exported water subsequently to be trucked back to the Delta and released. Further, the relationship between number salvaged and number entrained varies by fish size and species. To properly quantify entrainment, reliable salvage-to-entrainment relationships need to be developed based on experiments and modeling.

Even given these difficulties, several recent analyses have used proportional entrainment to address the importance to delta smelt population of entrainment by water exports from the south Delta (Kimmerer 2008, Miller 2011, Kimmerer 2011). Based on simulation analyses, Kimmerer (2011) reported that delta smelt losses on the order reported by Kimmerer (2008) could be almost undetectable in regression analyses and yet important to determining population abundance. The calculations behind quantification of proportional entrainment are numerous and complicated, and many of the assumptions need to be further verified and refined. Moreover, similar approaches and analyses are needed for other fish species entrained by water exports. As entrainment-rate estimates are further developed and refined, it is important to include explanatory and management-related variables (e.g., Old and Middle River flows, Grimaldo et al. 2009) as part of the analysis. Including the explanatory variables from the outset will enable more consistent and robust statistical relationships involving entrainment impacts to be determined.

2.6. Need to consider population diversity in the assessment of how species respond to water quality objectives.

Diversity in a population is related to its overall fitness, and higher diversity allows for populations to better absorb stress and respond to changing conditions. Chinook salmon possess multiple life history strategies (Healey 1991), and the Sacramento-San Joaquin river systems host 4 stocks that are distinguished by their adult migration timing and other aspects of their life history (Moyle 2002). Delta smelt show different rearing habitats (Hobbs et al. 2005) and adult migration strategies (Sommer et al. 2011b). Splittail in the Napa and Petaluma Rivers are genetically different from those in Sacramento, Cosumnes, and San Joaquin Rivers, and this difference may be related to differences in salinities of early rearing habitats and spawning migration distance (Baerwald et al. 2007). Maintaining population diversity is important for many species and should be a focus of active management.

Managing water to maintain the diversity and deriving appropriate water quality objectives require a firm base of science. Additional monitoring and laboratory experiments are needed to identify and describe phenotypic variability at key life stages and processes (e.g., timing of adult migration). Derivation of water quality standards also need to account for the drivers of the diversity, such as what flows or temperatures affect the range of migration timing (or habitat), rather than just its peak. Similar considerations of the variability in habitats and the variability of individual or cohort fish responses are needed to maintain diversity. In addition to new science on how water quality variables, and thus objectives, affect diversity in species of interest, studies are needed to examine how current and future climate changes may be substantially affecting the baseline and variability in flows.

Several principals contained in the Flow Criteria Report (SWRCB 2010, pg 5 and elsewhere) will support species diversity through water quality objectives: (i) flow criteria should reflect the frequency, duration, timing, and rate of change of flows, and not just volumes and magnitudes; (ii) inflows from Delta tributaries should be on a proportion of unimpaired flow and reflect the natural hydrograph; and (iii) flows should be ramped up and down to allow fishes time to adjust behavior and distribution and to avoid impacts associated with abrupt change.

3. Key Emerging Science

3.1. Pelagic fishes have more flexibility than previously understood.

Most of our current understanding about pelagic fish abundance trends (including the relationships with flow) is based on surveys sampling in the relatively deep channels of the Delta and Bays. Recent studies suggest that pelagic fishes may have more flexibility to use other habitats and geographical areas than previously understood. Juvenile striped bass have shown a strong apparent lateral shift away from deep channels towards shoals (Sommer et al. 2011a). Similarly, longfin smelt distribution has shifted to downstream bays and into deeper waters (Baxter et al. 2010). It is not known if these are active (i.e. behavioral) or apparent (higher mortality in historical areas) distribution shifts; however, behavioral flexibility is known for many estuarine fishes including striped bass (Sommer et al. 2011a). It is also possible that the two other primary pelagic fishes, delta smelt and threadfin shad, have similar flexibility. While the center of distribution of delta smelt is still in the low-salinity zone, the species has shown evidence of increasing use of Cache Slough Complex in the north Delta (Sommer et al. 2011b). Threadfin shad center of distribution used to be in the south Delta (Feyrer et al. 2009), but the species has recently been concentrated in the Sacramento Deep Water Ship Channel. These results do not mean that the historical low-salinity zone and deep-channel habitat are no longer important, but that pelagic fishes have more behavioral flexibility than was previously described.

3.2. Regime change may mute beneficial flow effects.

Despite the extreme landscape and hydrological variability in the Bay-Delta system, one of the remarkable patterns is that the abundance trends of many different estuarine species show associations with flow (Jassby et al. 1995). Examples include longfin smelt, American shad, starry flounder, and splittail. Recently, several of these relationships have become muted (Kimmerer 2002; Sommer et al. 2007; Baxter et al. 2010; MacNally et al. 2010), so while flow is still important, flow now provides much less “bang for the buck” than it did historically. One of the initial abundance shifts appears to be due to the food web effects from the introduced clam *Potamocorbula* starting in the mid-1980s (Kimmerer 2002), but the subsequent dramatic shift during the Pelagic Organism Decline (POD) after 2000 remains unexplained by any single factor (Sommer et al. 2007; Baxter et al. 2010; MacNally et al. 2010).

Baxter et al. (2010) propose that these shifts in abundance relationships represent a major regime shift in the ecosystem. They cite numerous major changes, including a decline in pelagic fishes and key zooplankton as well as a rise in aquatic weeds, introduced inshore predators, harmful algal blooms, and jellyfish. Regime shifts have been seen in other aquatic habitats worldwide and new regimes can be difficult to alter via management actions without major disturbances—regimes are thought to have a relatively large amount of inertia that cannot readily be changed and may not even be reversible to the original state (Beisner et al. 2003; Scheffer and Carpenter 2003). In the Bay-Delta system, flow manipulations within the operable range may not be able to shift the current ecosystem regime to a more desirable state (e.g. strong pelagic productivity) or a state reminiscent of prior conditions. Changing the present regime may require much more extreme forcing, such as a large-scale alteration of aspects of system morphology (e.g. levee failure from earthquake or flood; massive habitat restoration). However, it is difficult to predict the future regime and there is no guarantee that the new regime would be more desirable than the current one.

If indeed the Bay-Delta ecosystem has shifted to a new regime, then new ecosystem goals and metrics need to be defined – and these will need to be developed without the benefit of analysis of decades of past conditions.

3.3. Major improvements in juvenile salmon survival in the Delta requires broad-scale change in channel and bank morphology.

One of the biggest concerns for salmon management is relatively poor survival through the Delta. Delta survival has continued to decrease in some reaches despite efforts such as the Vernalis Adaptive Management Program to protect migratory juveniles (Dauble et al. 2010). Although telemetry studies on hatchery smolts suggests that survival of very large fish can be satisfactory (Perry et al. 2010), recent evidence suggests that a substantial percentage of salmon recruiting to the adult population are relatively small fish (fry and parr) that must rear in the Delta before emigrating from the estuary (Miller et al. 2010). It appears that the primary reason for low survival in the Delta is the lack of suitable juvenile salmon habitat and resulting high predation rates. The habitat requirements of juvenile Chinook salmon are fairly well understood and include shallow areas with relatively low velocities (but adjacent to higher velocity areas) with terrestrial or emergent vegetation. Such was the landscape of the historical Delta when there were extensive riparian forests and tidal marsh (Atwater et al. 1979). Unfortunately, most of the Delta now is comprised of steep, rip-rapped channels with minimal edge habitat or appropriate vegetation (Sommer et al. 2001). A key exception in the Delta is the Yolo Bypass floodplain; however, the current configuration of the floodplain provides poor connectivity to the river channels, so young Chinook salmon have limited access to the floodplain except during very large flood events. Thus the majority of downstream migrating juvenile Chinook salmon do not have adequate resting habitat or refuge from predators, and they have access to a relatively poor and limited food supply (Sommer et al. 2001; 2005; Jeffres et al. 2008; Henery et al. 2010).

The quantity and quality of Sacramento River habitat in the Delta is relatively insensitive to flow, at least within typical range of operations (i.e. non-flood). In other words, flow increases do not enhance access to shallow or vegetated areas because the geometry of Delta channels is so steep. The channels behave more like a “bathtub”, where higher water levels do not inundate substantially more area until the whole system spills into Yolo Bypass. The key point is that survival of young fish moving through the Delta likely will continue to be poor until there are major changes to the morphology (e.g. set-back levees; floodplain and inter-tidal habitat restoration).

3.4. Sub-daily hydrodynamics may be more important to juvenile salmonids than previously understood.

A long-held assumption in Delta studies is that "net" negative flows exert a strong influence on juvenile salmonid behavior and survival (Newman 2008a; Newman and Brandes 2010; Dauble et al. 2010). This assumption is also implicit in the NMFS recent use of a Particle Tracking Model (PTM) to evaluate Delta hydrodynamic conditions experienced by juvenile salmonids (NMFS 2009). Kimmerer and Nobriga (2008) demonstrate that particle fate, both in terms of destination and arrival timing, was very sensitive to river inflows and, to a somewhat lesser extent, on exports. They observed that tides acted only to “spread out and delay the passage of particles” and that the fate of particles largely reflects “net”, non-tidal flow. Thus, particle fates reported by PTM are largely determined by “net” flows. However, acoustic telemetry studies (Perry et al. 2010, Holbrook et al. 2009, SJRGA 2011), like earlier coded-wire tag studies (Baker and Morhardt 2001), have shown salmon smolts are strong swimmers; moving through the

Delta more quickly than tracer particles and not in correspondence with "net" flows (Baker and Morhardt, 2001). In addition to rapid, directed swimming behavior, juvenile salmonids are known to successfully navigate through non-riverine environments with weak or no "net" flow (e.g., lakes and estuaries). This navigation appears to be guided by polarized light and the Earth's magnetic field (Quinn 1980, Quinn and Brannon 1982, Parkyn et al. 2003).

Though "net" flows may be important to some species and ecological processes, our focus here is on juvenile salmon migratory behavior. A new analysis by Cavallo et al (2012) describes sub-daily hydrodynamics in the main stem of the San Joaquin River and shows "net" flows are largely unrelated to sub-daily hydrodynamics (Figure 1). The authors' description of sub-daily hydrodynamics in the Delta also appears relatively consistent with patterns of salmon movements observed in acoustic telemetry studies (e.g., Perry et al. 2010; Holbrook et al. 2009; SJRGA 2011). This new study also proposes a specific mechanism for how sub-daily flows may influence juvenile salmonid migration behavior.

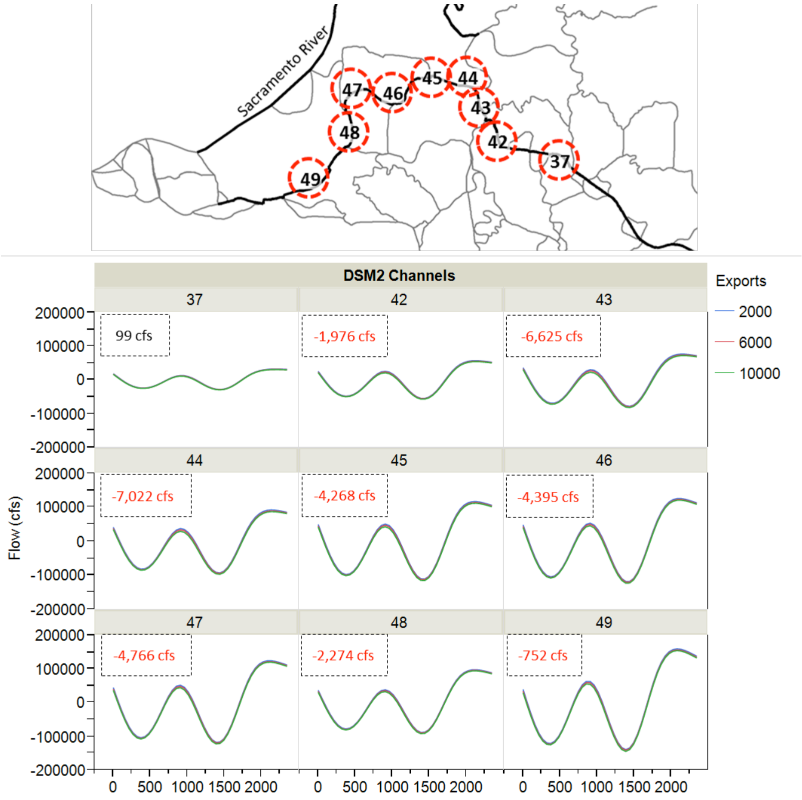

Figure 1. Flow at nine locations (DSM2 Channels) along the main stem San Joaquin River in the central Delta from the mouth of Middle River to Jersey Point (map in upper panel). Time of day in 24-hr format is on the x-axis, starting at 0000 hours and ending at 2345 hours. Magnitude of flow (cfs) is on the y-axis. Curve color indicates export level (2000, 6000 or 10000 cfs). Flow values inset within each graph indicates calculated "net" flow averaged across all three export levels. Data comes from inflow and export scenarios evaluated by Kimmerer and Nobriga (2008) and analyzed by Cavallo et al. (in review). Medium river inflow values were used (see Cavallo et al. for details), however sub-daily flow patterns at these locations were largely insensitive to river inflow levels.

Thus, Delta juvenile salmon studies and management may have become overly reliant on an assumed major adverse effect of “net” negative flows on juvenile salmon behavior and movement. Though “net” flow (and “net” negative flows in particular) may prove a useful indicator of juvenile salmonid migratory behavior and success, a sufficiently detailed mechanistic hypothesis for how this relationship might function needs to be clearly articulated. Overall, these new studies suggest that sub-daily hydrodynamics, not just “net” negative flows, should be considered when evaluating water quality objectives intended to benefit juvenile salmonids.

3.5. Managing for salmonid life-history diversity.

For some time, salmon management in the Delta has focused on relatively large salmon smolts (>75mm) with the objective of enhancing survival for these fish by providing conditions that move these fish through the Delta as quickly as possible (e.g., SJRGA 2007, 2011). This approach is based on the idea that larger smolts have a competitive advantage upon entering the ocean and are more likely to survive to adulthood (Hayes et al. 2008, Satterthwaite et al. 2012). However, a focus on large smolts arriving in the Delta within a relatively narrow window of time ignores the importance of life-history diversity in contributing to population stability and resilience (see Section 2.6). For example, if all salmon in a single year arrived in the Delta in May, drought conditions and high temperatures might cause low survival for the entire cohort and year-class. In contrast, if instead a fraction of the year-class out-migrated as fry in March they might experience improved survival (relative to May emigrants), thereby affording resilience to the year-class. Variable life history strategies within populations provide insurance against unpredictable environmental events that might otherwise cause year class failure or even extinction. Dependence on a single life history strategy among the Sacramento River fall-run Chinook is thought to be a major contributing factor to stock collapse in 2007-08 (Lindley et al. 2009; Carlson and Satterthwaite, 2011). The following management actions contribute to poor life history diversity:

- Lack of variability in flow regime. Predictable flow pulses or “flat-lining” of river discharge will enhance survival of a life-history type adapted to that particular flow. However, when flow conditions shift (as they inevitably will) the dominant life-history strategy, previously successful in the “flat-line” environment, may fail. Flow regimes should not disproportionately favor one life-history strategy (i.e. large smolts) over others (fry emigrants).
- Poor rearing habitat. Development of diverse life history strategies among juvenile salmonids are linked to the availability of floodplain and tidal marsh rearing habitats (Shreffler et al. 1990; Bottom et al. 2005a,b; Miller and Simenstad 1997). The rarity of such habitats in the Central Valley has undoubtedly contributed to seemingly poor life history diversity among Central Valley salmonid populations.
- Hatchery practices and management. Hatchery stocks exhibit reduced fitness and life-history diversity relative to wild stocks due to domestication effects (CHSRG 2012). When the proportion of hatchery fish on the spawning grounds becomes too high (>5% to 15%; Mobrand et al. 2005, Ford 2002, Lindley et al. 2007) loss of fitness and life-history diversity results. Recently available data suggests many Central Valley tributaries host hatchery proportions in excess of 50% (CDFG 2012); life-history diversity and fitness will likely continue to be poor as long as these conditions persist.
- Ocean harvest management. Life history diversity applies not only to juvenile emigration and rearing strategies, but also to diversity in age-at-maturity. Populations with greater age-class diversity among adult spawners will be more resilient to year class failures and less vulnerable to extinction. Ocean harvest rates

for the 2012 Sacramento Basin index were set at 44% (PFMC 2012), and have been much higher in past years (Pyper et al. 2012; Figure 2). This level of ocean harvest likely will reduce the proportion of age-4, age-5, and age-6 Chinook salmon that might otherwise occur on the spawning grounds.

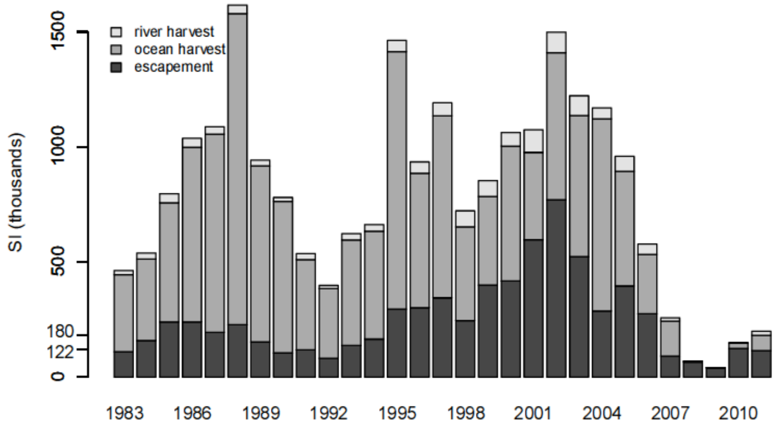

Figure 2. Harvest and escapement data for the Sacramento Index (SI) of fall run Chinook salmon. Harvest (light gray bars) exceeds spawning escapement (dark grey bars) in many years, indicating harvest rate of >50%. Source: CDFG 2012 Salmon Information Meeting Handout (https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=43348&inline=true).

3.6. San Joaquin River inflow is more important than previously understood.

The majority of inflow to the Delta comes from the Sacramento River (Brown and Bauer 2010), and operations in that drainage represent the major tool to meet Delta outflow objectives. While San Joaquin River flows are hydrologically less important, there is an increasing recognition of their disproportionately strong role in Bay-Delta productivity. While phytoplankton resources in the estuary are considered relatively poor (Jassby et al. 2002), the lower San Joaquin River represents a relatively enriched region (Lehman 2007). The contribution of these resources to the downstream food web is strongly regulated by San Joaquin River flow. Food web effects may not be limited to phytoplankton as San Joaquin River inflow is hypothesized to be one of the primary sources of the calanoid copepod *Pseudodiaptomus forbesi*. *P. forbesi* is a major food for key fishes such as delta smelt (John Durand UC Davis/San Francisco State University studies reported in Baxter et al. 2010). The bottom line is that San Joaquin River inflow appears to play a relatively strong role as a source of high-quality phytoplankton and fish-prey organisms.

A related emerging story is that San Joaquin River inflows may be more important than previously recognized for native fishes. For example, the San Joaquin River can be a substantial producer of splittail (Figure 3). Splittail year-class abundance, as measured by the US Fish and Wildlife Service beach seine survey during May and June sampling, suggests that Vernalis flows ≥ 3000cfs in March through May activates flood terraces between levees and also floodplains (e.g., Great Valley Grasslands) during high flows, both of which enhance splittail recruitment (Figure 4). Even during low flows, some splittail recruitment was detected every year (1994-2011) in the San Joaquin River. These benefits may not be restricted to splittail as the San Joaquin River may be similarly important for Sacramento blackfish and Sacramento pike minnow (R. Baxter, DFG, unpublished data).

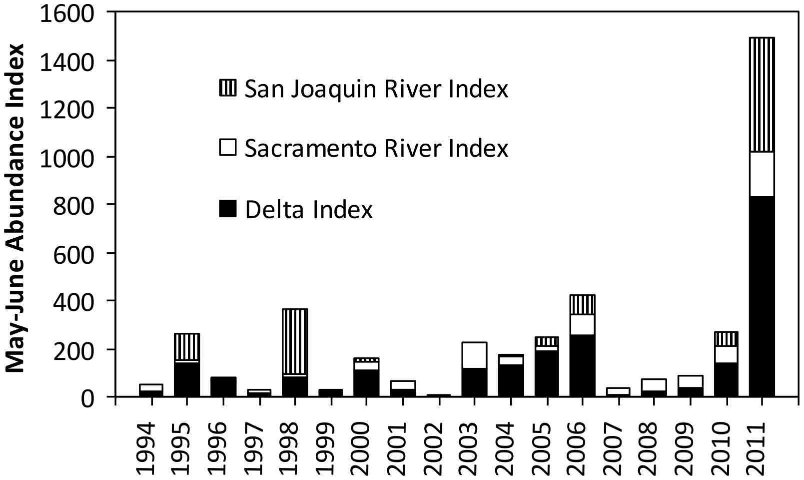

Figure 3. Splittail abundance in the US Fish and Wildlife beach seine survey, 1994 through 2011. See Contreras et al. 2011 for index calculation (http://www.water.ca.gov/iep/newsletters/2011/IEPNewsletterFinalSping2011.pdf)

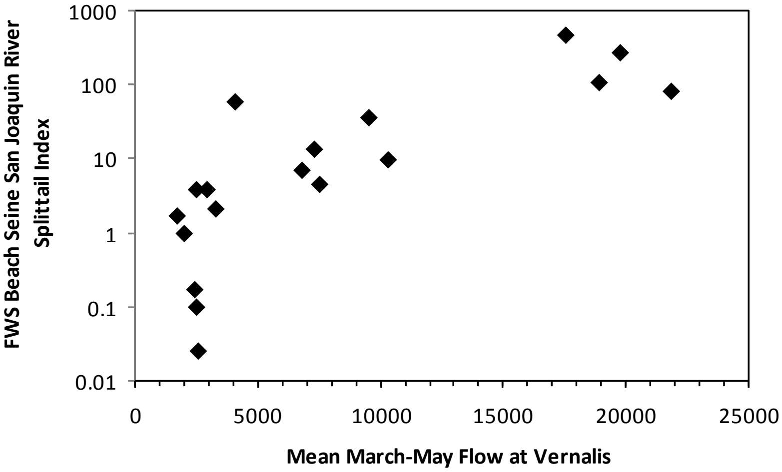

Figure 4. Relationship between US Fish and Wildlife San Joaquin River beach seine abundance of age-0 splittail (log10 scale) and mean daily March through May outflow at Vernalis from Dayflow, 1994-2011. Baxter unpublished.

3.7. Biological models are available to enhance understanding and to guide management.

Factors contributing to the decline of Central Valley Chinook and pelagic estuarine species are known and relatively well understood. However, the relative importance of different factors is uncertain, and this uncertainty diminishes our ability to effectively evaluate alternative management actions. Simulation models provide a framework for organizing information regarding the impact of changes in environmental variables (e.g., flow, temperature, exports, harvest, and physical habitat), for quantifying the effects of these changes on the abundance at each life stage (e.g., development, migration, and maturation), and for evaluating the resulting impact on overall population viability. Both scientists and managers have increasingly recognized the utility of life-cycle models for evaluating salmon population responses to management actions (Ruckelshaus et al.

2002), and a recent review of salmon recovery efforts in California's Central Valley recommended their use (Good et al. 2007). As noted in Section 1.5 above, several published biological simulation models (e.g. Zeug et al. 2012, Maunder and Deriso 2012) are available for Central Valley fish populations, and other models are in various stages of development or peer review (e.g., Rose et al. 2012, Hilborn 2010, Danner et al. 2011, Newman et al. 2012).

Life cycle modeling is accelerating in the Central Valley (reviewed by Rose et al 2011 for salmonids) and new models are expected to yield new insights and management guidance. However, these kinds of models should not be viewed as predictive of future conditions, but rather can be effectively applied to explore trade-off in alternative management actions. For example, evaluating available management actions for different life stages of a sensitive species will likely help to identify actions most likely to contribute to recovery.

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