LATE COMMENT

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To: State Water Resources Control Board

From: Invited Panel - Bay-Delta Workshop 1: Ecosystem Changes and the Low Salinity Zone (Jim Cloern, William Fleenor, Wim Kimmerer, Anke Mueller-Solger, Larry Brown, Steve Culberson, Cliff Dahm, Bruce Herbold)

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Re: Bay-Delta Workshop 1 – Ecosystem Changes and the Low Salinity Zone

Introduction

The 2008 "State of Bay-Delta Science" report (SBDS, Healey et al. 2008) revolved around the idea that the "Delta is a continually changing ecosystem." This report also noted that "change is inevitable and is necessary for the system to function properly since estuaries and deltas are dynamic, constantly changing ecosystems." Since then, we have learned a lot about historical, ongoing, and possible future changes in the Bay-Delta ecosystem and have developed new tools to study them. This has led to a fuller appreciation for the importance of changes that happen at different times, at different rates, or along different trajectories (e.g. slow, gradual changes versus rapid "step" changes). Many new studies have focused on the drivers of change, their interactions, and their manifestation as stressors on the Bay-Delta ecosystem. We have also begun to consider in greater detail how more rapidly changing, dynamic ecosystem components (e.g. flows) interact with more slowly changing, relatively stationary components (e.g. the bathymetry underlying the low salinity zone in the Bay-Delta), how this affects ecosystem processes in the low salinity zone and elsewhere in the estuary, and what changes in processes might mean for ecosystem management. The full spectrum of drivers of change, the changes themselves, and their manifestation in the ecosystem need to be considered to understand, plan for, manage, and adapt to future changes, including changes in flow.

The following information summarizes some new scientific insights about ecosystem change and the low salinity zone since the publication of the 2008 SBDS report that the panel deemed particularly relevant to the water and ecosystem management decisions under the purview of the State Water Resources Control Board (Board). It concludes with a series of recommendations aimed at achieving adaptable policies for sustainable water and ecosystem management. The panel will expand on these comments in its presentation at the September 5-6 workshop and will be happy to answer any questions that the Board might have.

1. The Bay-Delta ecosystem is in a perpetual state of change

Virtually every aspect of the San Francisco Bay-Delta system has been significantly transformed during the past 160 years. A recently completed study used new approaches and tools to explore historical ecological conditions of the Delta and changes that occurred more than 50 years ago (Whipple et al. forthcoming). This study showed that the historical, "natural" Delta landscape consisted of three regions with distinct hydrological and ecological characteristics and diverse native communities adapted to them. This new knowledge provides important "guiding images" (Palmer et al. 2005) that can help devise water and land management strategies that mimic, if not restore, at least some of the natural ecological processes that sustain native species and reduce the lasting impacts of historical changes. In the decades following the California Gold Rush, the historical landscape changed very rapidly and dramatically, but systematic documentation of these changes and their effects by long-term monitoring programs is available only for the last half century. Monitoring records since the 1950s show that freshwater inflow to the estuary has been reduced 40% by upstream consumption and diversions; sediment supply is half the supply rate of the mid 20th century; turbidity of Suisun Bay has declined fifty percent since 1975; primary production of the upper estuary declined by 80%,%, abruptly after the 1987 colonization by a nonnative clam; populations of native fish have declined to alarmingly low levels; the zooplankton community of the low-salinity zone is unrecognizable from that of the 1970s (Thomson et al. 2010, Cloern and Jassby 2012).

2. Abrupt ecosystem changes can be difficult to reverse

While some of the changes to the Bay-Delta system have been fairly gradual, others have been abrupt, such as the decline in primary productivity in the 1987 and a recent step decline in about 2002 in the abundance of four pelagic fish species (Thomson et al. 2010). Consideration of these different rates and trajectories of ecological change and their causes and effects have led some authors to explore the idea of ecological regime shifts in the Bay-Delta (Moyle and Bennett 2008, Baxter et al. 2010, Moyle et al. 2010,). Such abrupt shifts to new ecosystem "stable states" have recently been observed and described in many human-dominated ecosystems around the world (Carpenter et al. 2011) and are often the result of multiple interacting drivers of change that lower the resilience of ecosystems (Davis et al. 2010). They have also been shown to occur as a result of water management (e.g. Petersen et al. 2008) or climate shifts (e.g. Cloern et al. 2010). Abrupt regime shifts that affect whole ecosystems are worrisome because they may be especially difficult and costly to reverse, if the new regime is stable and resists further change. This means that management actions aimed at improving ecosystem conditions may not show positive effects for many years – delays should be expected and it may often take many years of implementation and monitoring to assess the effectiveness of management actions with some certainty. The present Bay-Delta ecosystem is clearly in a very different state than the pre- Gold Rush Delta. It is, however, not yet clear if the Bay-Delta system entered a new "regime" in the late 1980s or the early 2000s or if the current state is more transitory and so still able to respond quickly to management actions.

3. Ecosystem changes in the Bay-Delta have many causes

There is now broad scientific support for the idea that the profound transformations of the Bay-Delta system are the result of many drivers of change (reviewed in Healey et al. 2008, Baxter et al. 2010, DISB 2011, NRC 2012). Many of these drivers manifest as "stressors" that lower the resilience of the Bay-Delta ecosystem to additional changes. Because there are so many stressors and because they often interact in complex ways, the stressors to the Bay-Delta ecosystem cannot be ranked in relative importance to one another (NRC 2012, DISB 2011). They can, however, be grouped into four categories that require different management approaches (DISB 2011): global drivers/stressors, legacy stressors, anticipated stressors, and current stressors. A broad ecosystem approach that takes into account this broad range of stressors and their effects and includes adaptive strategies is needed to design conservation plans to sustain native communities and their supporting ecosystem functions (NRC 2012, DISB 2011). This kind of broad, scientifically-based ecosystem protection might, however, come at a high water cost.

4. Flow changes are ecosystem stressors

Flows of freshwater directly or indirectly affect almost all ecosystem processes and affect or interact with many other stressors in the system. Together with other changes, changes in flows into, through, and out of the Bay-Delta system have had lasting and profound effects on the ecosystem. The Delta Independent Science Board (DISB 2011) classified changes in flows along with the structural changes associated with storing, channeling, and diverting fresh water flows as both "legacy" and "current" stressors to the Bay-Delta ecosystem. They also anticipated that future changes in hydrology and water infrastructure would produce additional stress. While some of these changes have to do with global – and thus not regionally manageable – changes in climate and human demography, much can be done on a regional basis to ameliorate the lasting negative impacts of historical changes, mitigate current stress, and forestall or adapt to future stress associated with flows. Such actions, taken as part of a broad program of scientifically based ecosystem protection, might require substantial quantities of water. The DISB (2011) cautioned that as "changing climate increases stress on listed species, conservation may demand more water for environmental protection, further reducing the flows available for other uses" (DISB 2011). The weighing and balancing of the risks associated with the potentially high water cost of comprehensive, science-based ecosystem protection will likely not be based on a straightforward application of science (NRC 2012). Social and cultural factors will likely also be important in such decisions.

5. Flow changes affect the seasonal and year-to-year dynamics of the low salinity zone, a key region of the Bay-Delta ecosystem

The low salinity zone (LSZ) is a key region of the estuary for retention of organisms and particles and nutrient cycling, and it provides habitat for numerous organisms including delta smelt and striped bass (Turner and Chadwick 1972, Kimmerer 2004, Bennett 2005). Its location and extent is driven by the interaction of dynamic tidal and river flows with the regional topography. At high Delta outflows, the LSZ is sometimes located as far west as San Pablo Bay but more often is located east of Carquinez Strait and includes the shallow, open Suisun Bay with its connection to the productive Suisun Marsh. At lower outflows, the LSZ is located farther to the east and occupies the deep and spatially more constricted confluence of the Sacramento and San Joaquin Rivers. Under natural flow conditions, the LSZ moved according to a predictable annual rhythm with a westward position in winter and spring and an eastward position in summer and fall. The spatial extent of these seasonal shifts varied greatly from year to year because of interannual variations in precipitation and hence river flows (Dettinger et al. 2011). The location, extent and dynamic movements of the LSZ and its interactions with other parts of the estuary have been modified greatly by flow-related changes in tidal range, total tidal prism, the installation of the Suisun Marsh salinity control gates, and reduction in the extent of marshes and floodplains. The seasonal rhythm has become less clear and year-to-year variations have become muted, especially in the summer and fall. Recent modeling using new 3D modeling tools have greatly improved our understanding of LSZ movements and how LSZ position affects its areal extent, volume, and average depth.

6. Flow changes can have many ecological consequences, including in the low-salinity zone

Changes in flow regime may have benefitted non-native species over native species, although in many cases the exact mechanisms remain uncertain. The clam *Potamocorbula* which invaded the estuary in 1987 may have been one of the beneficiaries of the flow-related alterations to the LSZ

(Nichols et al. 1990), with repercussions throughout the LSZ food web. Before 1987 the LSZ usually had high summer phytoplankton biomass and moderately high zooplankton abundance and fish biomass. Since 1987 phytoplankton and zooplankton biomass, size, and production have been much lower while clam biomass and grazing have been high (Thompson 2005, Winder and Jassby 2010). In addition, low abundance indices of some fish species have been associated with a persistent eastward position of the low salinity zone in the fall (Feyer et al. 2007, 2010). Some researchers have suggested that increasing ammonium loading may have also contributed to the phytoplankton trends (Dugdale et al. 2007, Wilkerson et al. 2008, Glibert et al. 2011, Parker et al. 2012), although this hypothesis remains controversial. Comprehensive new studies are under way to better understand the processes that link physics, chemistry, and biology in the LSZ and determine its habitat value for native and non-native species. These studies include the Fall Low Salinity Habitat (FLaSH) studies that are part of a fall outflow adaptive management plan (USBR 2012). A publicly available draft report with results from year 1 of the FLaSH investigations is currently in review (see http://deltacouncil.ca.gov/science-event-detail/7070).

7. The Bay-Delta will continue to change and we can predict and plan for some of these changes

We know with a high degree of certainty that the Bay-Delta system will continue to change in the future as a result of “Major changes such as land subsidence, climate change, habitat alteration, water quality, population growth, water exports, invasion by non-native species, and in-delta physical changes” (NRC 2012). Sophisticated modeling tools, knowledge of previous changes, and experiences from elsewhere, are improving the ability to predict at least some future changes and their effects. Some changes seem likely in the near future, such as the establishment of quagga and zebra mussels in the South Delta which offers them favorable habitat conditions (DWR 2011) or reductions in some contaminant loads as new discharge permits are implemented. Other changes such as those associated with climate change may take somewhat longer to become apparent, but will likely present many ecological challenges as several recent modeling studies have shown (Cloern et al. 2011, Feyrer et al. 2010). Ongoing and planned changes in water conveyance and habitat restoration will produce additional ecosystem changes. Some such changes may be surprising. For example, modeling studies suggest that restoring aquatic habitat by flooding Delta islands can fundamentally change the hydrodynamic environment in the Estuary, with many ecological repercussions (Enright 2011).Outputs from these kinds of models can be used to anticipate future changes and then build contingencies into policies. For example, salinity standards for targeted fish species are grounded in the empirical relationship between freshwater outflow and “X2,” an indicator of the position of the estuarine salinity gradient. However, that relationship will change as sea level continues to rise, or following an intentional or unintentional reconfiguration of the Delta. Hydrodynamic models linked to climate models provide a tool for anticipating new flow-X2 relationships, but further work is needed on the links of X2 to fish populations. These kinds of analyses would allow the State Board to better understand the feasibility of sustaining today’s flow standards into the future, and then to consider alternative approaches if today’s policies are unlikely to be sustainable.

8. But future change cannot be predicted exactly – adaptation will be needed

Even with the best modeling tools we will never be able to predict with complete certainty how the estuary will change in the future. Policies and management strategies governing water allocation and ecosystem sustainability should be adaptable to changing circumstances. An example of such adaptability based on the consideration of a variety of possible scenarios is provided by a recent series of studies which envisioned and compared different futures for the Bay-Delta under different management strategies and trajectories of change (Lund et al. 2007, 2008, 2010, Moyle et al. 2012). Implementation of adaptable policies and management strategies requires constant vigilance. Relevant monitoring is needed to detect changes as they occur and additional studies are needed to understand why they have occurred. The sustained collection and synthesis of strategically selected environmental and biological data and associated research and modeling efforts are essential for detecting changes, providing early warning signs of regime shifts (Carpenter et al. 2011), and for informing resource managers when environmental changes are sufficient to trigger implementation of new policy actions.

9. Toward adaptable policies for water and ecosystem management: recommendations
Effectively dealing with the multiple challenges associated with past, present, and future changes to achieve sustainability targets is clearly not without cost, including possibly high water costs and associated risks to the California economy and human well-being. In its recent report on sustainable water and environmental management in the California Bay-Delta, the NRC concluded that "*hard decisions will need to be made about balancing different kinds of risk. These will be matters of policy rather than being the result of a straightforward application of "good science." Exactly because statistical correlations are not adequate to fully explain the responses of aquatic species to either flows or flow pathways, continuing the effort to better understand the processes that control the implications of both flows and flow paths is essential into the future*" (NRC 2012). This panel concurs and further recommends that

A. existing modeling tools and model outputs be integrated and applied to develop scenarios of future change in the Bay-Delta system geared specifically to meet the information needs of the State Board and other policy-making bodies whose management actions can be informed by anticipation of future changes;
B. existing monitoring and research programs be integrated and configured to detect and understand the anticipated changes;
C. analysis and synthesis of monitoring and associated research data be an ongoing, high-priority activity that is integrated with modeling and scenario development;
D. development of new monitoring, research, and modeling tools should be encouraged to reduce uncertainty in predictions and analysis; and
E. processes be established to efficiently and effectively communicate new discoveries from these activities so they can be applied in real time to adaptable policies for water and ecosystem management.

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