WORKSHOP SUMMARY:

Technical Workshop on Estuarine Habitat in the Bay Delta Estuary

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SUMMARY
Technical Workshop on Estuarine Habitat in the Bay Delta Estuary

Introduction

The Technical Workshop on Estuarine Habitat in the Bay Delta Estuary was initiated by USEPA, with support from the Aquatic Science Center (ASC), to obtain scientific input needed to inform EPA on California's Comprehensive Review of the 2006 Water Quality Control Plan for the Bay Delta Estuary. Gathering a number of recognized experts on the hydrology and ecology of the Bay Delta was an efficient way to hear current knowledge on estuarine habitat, tools for modeling and assessing conditions, and how biological indicators and ecological processes respond to movement of the low salinity zone.

More specifically, the purpose of the workshop was to:

- Increase our collective understanding about the attributes of estuarine habitat, and the tools we have for protecting it
- Characterize the response of biological indicators and ecological processes to changing locations of the low salinity zone (LSZ)
- Generate scientific information that EPA and others can translate into recommendations that support the State's Comprehensive Review of the 2006 Water Quality Control Plan (WQCP) for the Bay Delta Estuary

The following sections describe planning for the workshop and the workshop process itself. The workshop summary condenses the input from participants during the small workgroup sessions and the final plenary session. It captures the breadth of opinions, judgments, and viewpoints expressed without attempting to fact check statements, or reconcile / synthesize disagreements or contradictions. Finally, the facilitator's report provides my personal impressions of the workshop and the degree to which it achieved its stated purposes.

Workshop Planning and Process

Planning

A core planning group (Appendix 1) developed the agenda, process, and working materials for the workshop. The core planning group was composed of staff from EPA Region IX, ASC, and an independent facilitator. The goals of the workshop included increasing EPA understanding of estuarine habitat and the low salinity zone, ecological responses to changing locations of the low salinity zone, and scientific tools we have for learning more about the low salinity zone. Initial rough drafts of the agenda and workshop framework were developed by the planning group and sent to invited participants. The planning group incorporated comments and suggestions from invited participants and presenters that helped focus the four central questions in the workshop agenda.

The planning group provided three background documents to invited participants prior to the workshop in order to provide a common starting point and frame of reference for all workshop participants. These were intended as working materials and not as permanent reports subject to a formal review and revision process.

1. Modeling Estuarine Habitat in the Bay Delta (Appendix 2), summarized concerns about the effects of the LSZ, and its position in the estuary, on fish populations. It presented a brief overview of how X2, the 2 ‰ (parts per thousand) salinity isohaline (as measured in kilometers from the Golden Gate), has been used to

help manage key aspects of habitat in the estuary and suggested how newer three-dimensional models might improve this management tool.

2. Review of Scientific Papers and Summary of Key Findings (Appendix 3), summarized the results of 23 selected technical papers on X2, the low salinity zone, and ecological processes in the Bay Delta. The list was constructed through an informal process that included several scientists with a long history of involvement in research in the estuary. This product included a brief synopsis of each paper as well as a list of the major areas of agreement, disagreement, and uncertainty in the existing science on the LSZ and its role in the Bay Delta ecosystem.
3. Notes on Estimating X2 (Appendix 4) were prepared to accompany an excel workbook containing 1930-2011 DAYFLOW and X2 data for use by IEP. The last two pages of these notes contain notes about X2 and outflow values available in CDEC and the now discontinued DWR/IEP HEC-DSS database. A compilation of CDEC outflow (1994-present) and X2 (2007-present) data is available on EPA's website (www.epa.gov/sfbaydelta/activities.html under Delta Water Quality Standards).

Workshop process

The workshop agenda and process (Appendix 5) was designed to provide participants with additional technical information through a set of three presentations that focused on the historical ecology of the Bay Delta and the capabilities of current three-dimensional modeling tools. A series of small group sessions then maximized the opportunity for interaction between participants. Not only did the use of four workgroups increase the amount of parallel processing, but the round-robin structure enabled each small group to review the input of other workgroups. This workshop process helped ensure that the workgroup questions were considered from as many perspectives as possible. Finally, the plenary session at the end of the day allowed participants to express and respond to each other's final thoughts on the four questions, thus providing additional context to the internal workgroup discussions.

As explained in the process description attached to the agenda (Appendix 4) a participant was assigned as the reporter to each question with the role of following the assigned question as it rotated from workgroup to workgroup (see Appendix 5 for participants in each workgroup, workgroup leaders, and reporters). Reporters were thus able to capture how participants' input and perspectives evolved as questions were considered through multiple iterations. In addition, project staff observed the workgroups and collected additional, nearly verbatim notes that provided supplementary raw material for the workshop summary and for USEPA's internal use.

Workshop Summary

The following subsections present a synopsis of the comments related to each of the four workgroup questions as they were addressed by three workgroups in turn. This summary includes the points made in discussion, organized around specific topics related to each question and presented without judgments on their accuracy.

Prior to the workgroup discussions, three presentations in the morning highlighted key technical information intended to give participants a common basis of understanding. The three presentations are available online at http://www.epa.gov/sfbay-delta/activities.html (click on Delta Water Quality Standards) and include:

- Historical Perspectives on the Estuarine Gradient (Robin Grossinger, Aquatic Science Center)
- Modeling Estuarine Processes using SUNTANS (Stephen Monismith, Stanford University)
- Modeling Estuarine Processes using UnTRIM (Michael MacWilliams, Delta Modeling Assoc.)

Question 1: Points of agreement, disagreement, and uncertainty

What are the key points of scientific agreement, disagreement, and uncertainty surrounding estuarine habitat and aquatic life in the Bay Delta Estuary? How could scientists and agencies "manage the uncertainty" while advancing the protection of water quality and estuarine habitat?

Habitat

The low salinity zone (LSZ) is not equivalent to estuarine habitat. Estuarine habitat encompasses the range from 0 to 35 ppt salinity and the LSZ is just one part of the overall gradient. Other gradients and important aspects of habitat in this estuary include:

- Salinity – different species and life stages occur in defined salinity ranges
- Temperature – particularly important in bioenergetics, but also as a lethal limiting factor
- Turbidity – important in assisting feeding and evading predation
- Food supply – has changed in composition and/or abundance at all trophic levels in recent decades
- Predation – some changes have enhanced predator effectiveness
- Connectivity among habitats – spawning habitat must be connected to rearing habitat
- Geometry – depth, area and volume of water, and flow are basic elements of estuarine habitat
- Variability at all times and spatial scales, both longitudinal and horizontal

Limiting any essential element of habitat will limit the quality of the habitat. Of these essential elements, many have changed.

Habitat against the shoreline is important, but there is uncertainty about what is going on at these edges. This should be addressed through additional measurements.

Providing a quantity of habitat, or predicting the quantity with models, is easier than predicting or defining / ensuring the quality of that habitat. There were a range of ideas about what constitutes high quality habitat. However, greater landscape diversity provides more temporal and spatial variability in habitat and this variability creates resiliency because it increases the chance species will find what they need. Connectivity between diverse habitats is also important for resiliency. Habitat has to be at the right scale to be effective.

Low salinity zone (LSZ)

The physical attributes of the LSZ depend on where it is in the estuary and uncertainty regarding the effects of its position can be addressed through measurement. There is more certainty regarding the nature of the longitudinal salinity gradient, but less regarding the horizontal gradient. The LSZ is in the middle of the range of habitats. Some physical properties of the LSZ have changed, e.g., it is getting less turbid, the shallow portions of Suisun and Grizzly Bays are getting shallower (losing sediment), and chlorophyll has gone down. There has been a decrease in the variability of fall X2 but it is not clear to some whether this is important.

The LSZ is very productive relative to other parts of the San Francisco Bay-Delta system. However, productivity is decreasing, though there is disagreement on how/why the decease is occurring, e.g., grazing vs. ammonium vs. both. There is uncertainty about the extent of the importance of ammonium to primary production. If productivity in the LSZ increases, there are large uncertainties about how much of this increase would go to pelagic (fish) and how much too benthic (clams) components of the system. If we do increase productivity, it would be better to do so in the spring.

There are large scale declines over time in the abundance of species, especially pelagic species, but there is not good information, and a wider range of opinion, on the cause(s) / mechanisms leading to these declines. The role of the LSZ in these abundance declines is uncertain. For example, there is a larger risk of entrainment when the LSZ is upstream but disagreement on the importance of this to populations.

We know the importance of salinity for aquatic life and the LSZ is an important measure of estuarine habitat for some species. There is more certainty about the importance of the LSZ and flow for resident pelagic species, but less so for salmon and sturgeon. Variability in the LSZ is essential for resident fish but not so much for salmon and sturgeon. Ocean harvest, hatchery output, predation, and conditions in tributaries are more important for salmon than the LSZ. Some species benefit from more saline conditions (higher than 2ppt) but these are generally species of less concern.

The location where high salinity meets low salinity can provide a lot of useful information about the estuary. But we have focused much effort on the physical aspects of the estuary (e.g., geometry and hydrology) and not so much on ecological processes. This results in a very poor capability to predict biological outcomes, a gap that needs more attention.

Master variable

Discussion of a possible "master variable" highlighted fundamental disagreement. Some think that flow is the master variable, while others believe changes in nutrients are the primary driver. Some think the idea of any master variable or essential attribute is flawed, with declines in abundance related to multiple factors. However, it is hard to find any indicator that is not affected by flow and landscape. Everything is affected by flow, but not the other way around.

The benefits associated with maintaining the LSZ at a specific location are probably achievable at lower flows through landscape or other changes to the estuary.

Uncertainty

The proper response to uncertainty depends on the nature of the uncertainty. If we are uncertain regarding fundamentals such as what is the major stressor, e.g. flow versus changes in nutrients, then there is no clear path forward. However, if we are uncertain regarding the details, then we can measure and adapt.

Uncertainty, based on statistics, has been used as an excuse for no action.

We are uncertain as to the appropriate scale for heterogeneity, but it should be scaled to the available tidal energy.

Other input

A few comments were made that did not engender much reaction or discussion:

- We know something about fish and zooplankton, but we don't know much about microbes, which are involved in important ecological processes
- We don't know as much about wetlands (seasonal and permanent) and the species that use them, as we do about open water
- Historical change has resulted in a shifting baseline, a changing view of what constitutes a good population
- We should design landscapes to accommodate connectivity, scale, and the location of favorable habitat features

Question 2: Need to update management approach

What is needed to update and improve the State's current approach of managing estuarine habitat with a springtime salinity standard (FEB-JUN)? What key scientific findings and emerging modeling techniques should be applied?

The X2 standard: pluses and minuses

When the X2 regulations were originally put into place, it was based primarily on a flow – abundance relationship, not a habitat volume or area relationship, and with less focus on or understanding of the mechanism (s) underlying the relationship. However, there were arguments in the early 1990s that increased productivity was related to positioning X2 near shallow habitat.

There are several species involved; it's unrealistic to expect one metric to represent one ecological function for these different species. X2 provides an index of multiple functions for different fishes. Perhaps the current standard is the right tool, but its implementation is confounded because it was thought of as controlling one variable of importance to all fish, rather than multiple mechanisms that affect different fish differently.

Suggestions for improving the current approach

Extend the salinity standard back a few months into December would help address concerns that longfin smelt eggs are incubating starting in December and we may be missing a benefit by not protecting outflows during that period. This might not need to happen every year but only in the critical years. This would require more basic research to better understand the functional relationship between different life stages and outflow and X2 position.

De-discretize the X2 trigger points (e.g., the Roe island triggers) and make the X2 requirement responsive to the continuous nature of the flow-abundance relationship. The standard would then have no trigger points and a finer temporal scale than the one-month increment. However, the tidal excursion in any given day is so great that it raises questions about what the habitat really is when the standard is applied.

Develop the capability to directly update measurements of bottom salinity in real time.

Consider other indicators of flow, such as something that captures the temporal variability in flow. For example, pulses may be very important regardless of where X2 is positioned.

Link the regulations to underlying mechanisms to the greatest extent possible. This would involve improving the relationship between the X2 management and a more refined description of the mechanisms that are indexed by X2 and their relationship to species biology. For example, a transport mechanism for a particular fish species may produce a different X2 standard than would a food production mechanism. This would involve working species-by-species (for key species) to establish what drives species abundance and what their habitat needs are, which would help in accounting for the expected outcomes of increased flows. Any links between abundance and outflow / X2 can contribute to an aggregated outflow / X2 standard. Any potential X2 recommendation should be clear as to the *uncertainty* associated with it. However, while mechanisms are helpful for refining and optimizing regulation, they are not required. When knowledge of mechanisms is lacking, the empirical relationship between flow or LSZ position and fish population response is more than sufficient to establish a regulation.

Expand the range for adaptive management by crafting more than one set of standards. For example, manage outflow for nutrients in one year and LSZ position (or something else) in another year. There is more storage south of Delta now than there was in 1995, which provides additional flexibility in years that call for reduced exports.

Take a year-round approach (perhaps based on water-year type) so that the consequences of spring outflow recommendations do not create adverse effects in the fall. For example, if abundance is just as good when X2 is at 74 as when it is at 65, then X2 could be set where it costs less water in spring, leaving more water available to support habitat in the fall. This would require a more holistic standard that included a fall X2 standard that acknowledges upstream storage conditions.

Improve the assumptions in the equations that relate X2 to other water quality conditions (e.g., stratification). The assumptions are currently very conservative and better models could potentially allow more goals to be achieved with the same amount of water.

Require an overall cost-benefit analysis of incremental changes in outflow. For example, if the water costs of Roe Island are high, ensure that the policy has achieved an acceptable marginal benefit for that water increment.

Conduct direct measurement of X2 on a more continuous scale, at least for a few years to improve the calibration of the current interpolation algorithm.

Conduct a multi-day intensive workshop to develop the justification that links each species' stressors to particular outflow amounts and LSZ positions.

Include the following question as part of the decision process: "*If you have ___ [limited] water to spend, how would you allocate the water*?" For example, generate as many Chipps Island compliance days as possible.

Think more explicitly about fish downstream, in the pelagic zone, that don't usually receive as much attention, e.g. starry flounder and Pacific herring.

Broaden the definition of LSZ-related habitat. It is not just the volume between two narrow salinity boundaries (e.g. ½ -6 psu, instead, for some species, it should be measured from "where the lower boundary was" (e.g. the volume *up to* 6 psu).

New knowledge that can improve LSZ management

There are scientific discoveries and new modeling techniques that should be applied to managing the LSZ.

New models and tools include:

- Life cycle model
- Turbidity model
- Three-dimensional modeling of habitat
- Bioenergetic models
- Foodweb models
- Sensor arrays
- Otolith microchemical techniques useful for determining natal habitat and conducting retrospective life history analyses

Apply more consistently the improved capacity to build conceptual models and tie these to study plans and quantitative studies.

Develop quantitative models of biological processes, which would allow for more rigorously addressing biological hypotheses.

Better define the behavior of fish habitat (conceived more broadly) in relationship to LSZ position by developing budgets for food plankton, turbidity, and other parameters. Optimizing water flow for production of certain key habitat features requires a better understanding of what needs to be optimized, in terms of habitat features, for each of the different species.

Build on the current capability to develop models predicting when, where and how much phytoplankton growth occurs under different LSZ positioning scenarios by addressing where, when, and how food is being *transported* into the various habitats (e.g., Is it locally produced? Is it advected in?). This is particularly critical for evaluating the food web impacts of wetland/floodplain restoration efforts

Parse out the effect of outflow temporally and spatially to estimate when outflow gets you the most bang for the buck in terms of food production, turbidity, or overlap with critical life history needs of the species.

Historical evidence reveals that some fish species of concern have declined since the X2 relationship was put in place, which suggests that perhaps regulation of X2 for purposes of protecting these species is not warranted, or that the situation is more complex than the original conceptual model envisioned (e.g., X2 may be a surrogate for Sacramento River inflow for longfin smelt). On the other hand, this sequence of events could also be interpreted as a poorly designed and implemented regulation, rather than an incorrect metric or conceptual model. For example, the failure to trigger the Roe Island requirement in many years (achieved by reinterpreting the regulations and manipulating reservoir releases) and the discrete nature of the standard temporally and spatially (e.g., not recognizing the value of each increment of LSZ movement/outflow improvement) may have led to a failure of the regulations to actually implement the conceptual model.

Question 3: Drivers

> *What are the drivers in the quantity of estuarine habitat during each season of the year? What are the drivers in the quality of estuarine habitat, including the location of the LSZ, during each season of the year? What biological indicators respond to changing locations of the LSZ between the Carquinez Strait and the western Delta? At the workshop, you'll be asked to fill-in the attached chart of Biological Indicators and Metrics. A sample is attached to stimulate your thinking, and you're encouraged to come to the workshop with ideas for completing this chart.*

Workgroups produced the followings lists of drivers in several categories, along with any key issues or assumptions that influenced or bounded their identification of items listed.

3(a): Drivers in the quantity of estuarine habitat during each season of the year?

Issues/Assumptions

1. Habitat: Focus on LSZ (1-6 ppt) as "habitat". Note, however, that this is based on averaging, both spatially and temporally. There is obviously more variation
2. Quantity: Focus will be on area and areal extent
3. There is much more certainty about the drivers (below); however, processes are likely much more important to organisms and are much less well understood
4. The first three drivers below are generally the most important
5. Spatial gradients vary depending on where the LSZ along the gradient of the estuary
6. The responses to drivers will vary by the type of species. For example, benthic organism responses are different because they occupy more fixed locations
7. Participants struggled with the distinction between quantity and quality; both are obviously important and interrelated
8. Except where indicated, most drivers apply to all seasons

Drivers

1. Landscape, bathymetry, and geography (the effect of landscape has been relatively underappreciated until recently)
    a. Difference of basic geology/geometry in different parts of the delta
    b. Channelization
    c. Levee building, land drainage/reclamation

    d. Levee failure/land inundation
2. Water control structures with highly seasonal operations
    a. Salinity control gates
    b. Flow control gates as at Old River and Delta Cross Channel
3. Flow, Lots of variability in this factor
    a. Rivers, watershed, local tributaries
    b. Need to consider component parts:
        i. Inflow
        ii. Outflow
        iii. Exports
    c. The previous components of flow are affected by multiple factors including:
        i. Flood management
        ii. Flow and temperature requirements
        iii. Water demand
    d. The previous components and factors all vary by season
4. Antecedent conditions affect outcomes
    a. Previous month
    b. Previous seasons
    c. Previous year
    d. Protracted drought
5. Tides
    a. Strong effects of the spring-neap cycle
    b. Spring-neap differences strongest at the summer and winter solstices
6. Wind
7. Barometric pressure
    a. wind
    b. Barometric pressure changes can change the location of the LSZ even without wind.

Question 3(b): Drivers in the quality of estuarine habitat during each season of the year?

Issues/Assumptions

1. Quality is assumed to apply to biota
2. Focus is on LSZ

Drivers

1. 1 Physical habitat that can affect organisms directly
    a. Depth
    b. Turbidity
    c. Salinity variation (some differences about the relevance of this factor given the other drivers listed below)
    d. Vertical stratification
    e. Vertical shear
    f. Lateral shear
    g. Temperature
    h. Connectivity
        i. Examples include:
        ii. Channel & off channel areas
        iii. Marsh channels to main channels
        iv. Marsh plains and channels
        v. Channels and adjacent bays
    i. Salinity control structures

j. Gates
    i. Change salinity distribution
    ii. Change connectivity
    iii. Change transport
2. Physical and biological factors that can affect fish food
    a. All of the above PLUS:
    b. Nutrient loadings
    c. Residence time
    c. Light availability
    d. Food availability
        i. Phytoplankton
            a) Biomass
            b) Composition
        ii. Zooplankton
            a) Biomass
            b) Composition
        iii. Microzooplankton
            a) Biomass
            b) Composition
        iv. Macroinvertebrates
            a) Biomass
            b) Composition
        v. Bioavailable carbon
            a) Quantity
            b) Composition
3. Structures
    a. Anthropogenic, e.g.,
        i. Pilings
        ii. Mothball fleet
        iii. Marinas
        iv. Riprap
        v. Flow control structures
    b. Organic
        i. Submerged aquatic vegetation
            a) Natives (e.g., *Stichenia*)
            b) Invasive (e.g., *Egeria*)
        ii. Floating aquatic vegetation (e.g. hyacinth and South American Sponge plant)
        iii. Intertidal wetlands
4. Predation / competition
    a. populations & distribution
        i. striped bass
        ii. jellyfish
        iii. birds
        iv. marine mammals
    b. harvest
        i. recreational
        ii. Commercial (?)
        iii. incidental
        iv. poaching
        v. scientific
    c. Competitors

    i. Populations and distribution
        a) Jellyfish
        b) Clams

5. Biological
    a. Predation risk
    b. Upwelling zones
6. Chemical
    a. Contaminants
    b. Dissolved oxygen
    b. pH

3(c): Biological indicators that respond to changing locations of the LSZ east of the Carquinez Strait?

Issues/Assumptions

1. Focus is on factors that change in response to LSZ position, NOT on all possible things that could be measured
2. Distinction between "things that respond" and "things that are associated"
3. Focus on biota
    a. Some participants suggested broadening metrics to other important factors such as turbidity and temperature
4. Historical record doesn't include full range of conditions needed to fully evaluate this issue
5. The long-term data set is limited by the frequency and timescales of the data
6. Many metrics are supported by actual data. Several metrics are associated with a high degree of uncertainty, but are nonetheless plausible

Metrics

Benthos

1. Corbicula
    a. Density
    b. Biomass
2. Corbula
    a. Density
    b. Biomass

Food

1. Phytoplankton
    a. Distribution (broad scale/fine scale)
    b. Availability (uncertainty about actual degree of response)
    c. Composition (uncertainty about actual degree of response))
    d. Net productivity (uncertainty about actual degree of response))
    e. Patchiness
2. Zooplankton.
    a. Ditto to above
3. Harmful algal bloom occurrence
    a. Distribution
    b. Density

Fish and Macroinvertebrates

1. Delta smelt
    a. Abundance (controversial)
    b. Distribution
    c. Health and condition (uncertainty)
2. Longfin smelt
    a. Abundance

    b. Distribution
    c. Health and condition
3. American shad
    a. Distribution
    b. Abundance
4. Splittail
    a. Distribution
    b. Abundance
5. Starry flounder
    a. Abundance
6. White sturgeon
    a. Distribution (uncertainty)
    b. Abundance (uncertainty)
7. Fish community composition
8. Neomysis
    a. Abundance (uncertainty)
    b. Distribution
9. Crangon
    a. Abundance
    b. Distribution

Other Metrics
1. Predation rates (uncertainty)
2. Wetland plant diversity
3. Scoter and scaup distribution

Question 4: Modeling

> *Given the historical and present-day relationships between the LSZ and the landscape of the Bay Delta, how can models be used to forecast the response of biological indicators to changing precipitation patterns, rising sea levels, and restoration scenarios?*

Components

If modeling focuses on just the LSZ it will miss most of the important factors.

Flow-based questions can benefit from the three-dimensional tools that are available now.

Forecasts of turbidity and temperature will lead to forecasts of primary production. Meteorological data, particularly the fog line, are needed to predict temperature.

It is important to know what is going on at the land water interface because small scale landscape features result in heat exchange. However, sampling only occurs in deeper water accessible by boat.
Predation is an important parameter and small fish avoid clear water because of the higher predation risk. Predation may be involved in the fact that X2 used to be connected to delta smelt but that relationship is now not so clear. It may be hard to predict how shorelines will be affected by sea level rise.

Slower water velocities lead to more cyanobacteria.

The channels in Elkhorn Slough are effective at soaking up nitrogen from the Salinas River and that mechanism may function in the Bay Delta as well.

Integrating biological and physical models

It seems that other estuaries have a three-dimensional primary production model and the Bay Delta does not.

None of the models available today can take vegetation into account. The primary productivity models are crude and thus can't display temporal and spatial variability. The biological models are less sophisticated than the hydrodynamic models and it has been more difficult to measure and model biological parameters and processes. There has been some unease with linking biological and physical models and it may be worth understanding modeling's weak links and its limitation in terms of producing clear cut answers / predictions.

Biological processes are important, which raises the question, as one participant expressed it, "Why do we have a Rolls Royce hydrology modeling capability when the biological data and modeling capability are only Pintos?" Dick Dugdale wants to develop a model that would calculate primary production to see if ammonium plays the role hypothesized for it. However, the phytoplankton model hasn't changed since Di Toro's model. Growth rates and grazing data are rudimentary but there is decent chlorophyll model. Dugdale is interested in knowing the concentration of phytoplankton and its export to Suisun Bay and suggests modeling the process. Despite this, other biologists have less interest in modeling in the Bay Delta. This may reflect their background and training, as well as the concentration of funding for modeling in DWR. It may be useful to attract scientists with experience in such modeling in other systems, such as the Great Lakes.

An experiment in the 80's involved slowing down water in the Delta in the spring and produced a large diatom bloom. Similarly, the Sacramento Ship Channel has more delta smelt and lots of chlorophyll and zooplankton. There is enough data and information to begin to pull together the physical and biological models. This would involve connecting physics to nutrients to algae / phytoplankton to zooplankton to delta smelt as a straightforward set of linkages. Any of the existing physical models would lead to the same general results, which could then be layered onto the biology. There are some simple things that could start to provide insight; for example, overlaying several parameters (e.g., temperature, salinity) shows that delta smelt habitat has shrunk.

It is important to begin to integrate physical and biological models but this does not require a new model. Knowledge exchange between biologists and hydrodynamicists, along with attempts to integrate existing data and models, would be a good starting point. Don't be too ambitious and try to model fish immediately; reduce the dimensionality of the problem. Begin with turbidity, temperature, and chlorophyll. Results from physical models may need to be scaled down to fit the level of sophistication or resolution / dimensionality of biological models. In this integration effort, special studies on smaller scales would be useful. For example, the Liberty Island / Cache Slough situation illustrates how there can be high production in the tributaries but none in Cache Slough because of volume, dilution, and mixing factors. Because of the cost of measuring biological parameters, conceptual models and estimates of processes are useful starting points, followed with instrumentation and data collection as understanding improves.

Restoration modeling

Modeling habitat restoration in the Delta is a different challenge and will require new expertise and models. There are not many wetlands in the Delta to work with (in terms of data gathering and modeling) and it is difficult to predict biological outcomes for a habitat that has not been there for 100 years. For example, some managers are thinking that shallow water restoration will produce good food conditions for smelt but research elsewhere suggests this may not be true. And it is not clear that enough is known about sediment supply to predict future Suisun Bay restoration scenarios.

It will be important to work with what's available and manage expectations. Modeling efforts will be more successful if they are focused on a specific location and project.

In addition, restoration involves different stakeholders and perspectives.

Modeling process
Modeling is a sociological process and difficulty in dealing with this aspect is an important impediment to more integrative modeling; this issue has not always been dealt with adequately in the past. Any attempt to integrate biological and physical models will require multidisciplinary teams, better communication, and consistent follow-through. Focused workshops could be an effective way of bringing together the different parties. For such workshops to be effective they must focus on a tightly and clearly focused problem (e.g., what do the three-dimensional flow fields do for food resources for zooplankton at Chipps Island?).

Models' ability to capture secondary indicators and then connect these to primary indicators should be evaluated. For example, can models connect delta smelt abundance to turbidity?

Models have improved over the past several years for many reasons, but partly because of the interaction between data collection and modeling.

Final plenary session
Following the workgroup sessions that focused on individual questions, participants reconvened in a final plenary session (see Agenda, Appendix 5) to hear summaries by the four reporters and then discuss issues highlighted by the earlier workgroup process. The discussion was prompted by questions from the facilitator and centered on the following three areas. As for preceding material, the following is based directly on participants' comments.

Historical ecology

While some participants had been aware of the historical ecology (e.g., information in Robin Grossinger's morning presentation) of the Bay Delta, this information was novel for others. For example, the incursion of salinity in the past was less, and the resistance to tidal incursion greater, than some had understood. Many factors may have contributed to this resistance (e.g., diversity of channels, discontinuity of channels, natural reservoir storage, fewer straight channels) and it would be interesting to see these older historical processes modeled. However, current three-dimensional models have large data requirements. Inputting historical bathymetry into models is relatively simple, but flows / hydrology would be difficult, especially developing a plausible range for base flows.

One way to conduct such modeling would be to begin with simple calculations and explore smaller elements of the system to see how they might work, addressing issues such as the size of the flood basins, the volume of water they could hold, and how tides would propagate in a restricted network of small channels. There are some historical data points, such as the estimated two foot tide in Sacramento in about 1850, that could help establish boundaries for such modeling.

Water and the landscape are important driving factors that determine habitat and quality and the historical perspective is not currently part of the discourse and the historical perspective does not inform everyone's view of the system. In some respects the historical perspective is revolutionary.

Historical information relates to the concept of unimpaired flow, something we know is not natural but that is considered close enough to be useful. The morning's presentation showed that the natural hydrograph and where the water travels are probably enormously different from the concept of unimpaired flow. It is possible that the natural hydrograph is enormously important. This has implications for restoration planning, particularly the issue of how wetlands and islands affect salinity intrusion.

Modeling

The hydrological models are fairly robust but the models that could predict the biological response (e.g., of phytoplankton and fish) are not as well developed or reliable. It is curious that there is not yet a three-dimensional phytoplankton model for the Bay Delta. It would be useful to identify the opportunities for and constraints on improving the biological models and establishing realistic expectations. These biological models would not function like engineering forecast models but it would still be possible to learn a lot about system behavior. Several participants urged that the needed knowledge and tools are available and that such an effort should be undertaken as soon as possible. More integrated models would help inform discussions about ammonium, benthic grazing, and other issues. However, the goal should be to produce models that are only as complex as they need to be and to ensure models are intelligently applied.

An effort to integrate physical and biological models should match levels of sophistication between the different types of models and it may not be wise to immediately attempt three-dimensional modeling of fish responses. Knowledge about higher trophic levels could inform thinking about the integrated models even if they are not explicitly modeled. Phytoplankton would be a good starting point, with the expectation that models would predict biomass fairly well but not do well on fluxes and where plankton are in the water column. One suggestion was to involve Jim Cloern and Dick Dugdale, who are conducting modeling of the South and North Bay, respectively, and have them compare their approaches and results.

In addition to predicting how biological parameters might respond to physical changes, an integrated set of models could help examine a more detailed set of potential costs and benefits of different approaches to X2 management. For example, models could help understand the unintended consequences in the fall of decisions about X2 management in the spring by evaluating the cost-benefit tradeoff of incremental increases in X2 in the spring. Modeling can also be used to help understand the hierarchy of mechanisms that affect ultimate indicators of concern. Increased understanding can then in turn be used to revise monitoring programs to produce data more useful for improving modeling tools. In other words, modeling, interpretation, and data gathering should be viewed as one integrated and mutually supportive set of actions that inform and build on each other.

Habitat

The use of the term “habitat” to refer to the LSZ is problematic and it was suggested that this term, especially as used synonymously with the LSZ, should be removed from participants’ vocabulary. Habitat means different things to different species at different times and places and is an n-dimensional hyperspace. When the term encompasses all dimensions it can become too broad to be useful; when narrowed down to a single species’ particular requirements at one place or time it can be unhelpful for broader management needs. However, the better the understanding of the mechanisms that underlie relationships between species and aspects of the physical environment the better we are able to manage these species. Habitat can be thought of in two useful ways. First, it can refer to aspects of the estuary that are useful, but extremely general, markers (e.g., wetlands). Second, it can be defined as a species’ requirements, only the first few dimensions of which are relevant. One approach would be to use the historic data set to build a description of species-specific responses and mechanisms, with the goal of developing a multispecies management framework. This would be in contrast to the current approach, focused on the LSZ, which some participants described as relevant primarily to delta smelt.

The LSZ is one aspect of habitat; a more useful way to discuss this would be to identify species of concern and identify their requirements. It is also important to keep in mind that management of X2 has downstream effects, including as far as exchange out through the Golden Gate. As understanding and modeling tools improve, it may be possible to conduct experiments that attempt to increase the amount of phytoplankton in the system and to manage its composition.

If contaminants are the primary problem for a fish species, then it would not be productive to define the problem in terms of a lack of sufficient habitat. However, there are regulations and management initiatives that focus on contamination in the Bay Delta. In addition, USEPA's Advance Notice of Proposed Rule Making, issued in 2011, was intended to focus on both the positive things species need (e.g., habitat) and the negative impacts (e.g., contaminants) that could affect populations. Species need a place to live that is also free from contamination. The Water Boards and other agencies are addressing both types of issues. This particular workshop is focused on the estuarine salinity gradient; other issues (e.g., contaminants) are being dealt with in other venues.

Facilitator's Report

Prepared by Dr. Brock Bernstein

The following are my personal reflections on the structure, process, and outcomes of the Technical Workshop on Estuarine Habitat in the Bay Delta Estuary, held March 27, 2012 in Sacramento, CA.

Overall, I found the workshop to be a productive step toward sharing information, bridging gaps in the understanding and interpretation of key concepts, and developing a shared basis for moving forward on improving the scientific and technical tools for managing key aspects of the Bay Delta's ecosystems.

Workshop planning

The conference calls and email exchanges prior to the workshop were adequate for organizing the workshop and developing the agenda and other materials. Team members' roles were well defined and timelines and interim deliverables were clearly identified and tracked by the USEPA project team. The planning and logistics were extremely well managed and I was impressed at the USEPA team's openness to input, even as the workshop agenda and materials were being finalized. For example, the presentation content and draft workshop questions were revised a few days prior to the workshop based on input from the presenters and other interested parties, in order to better accomplish the workshop's goals.

Workshop structure and process

The morning agenda included three presentations, one on the historical ecology of the Bay Delta and two on advances in tools for modeling hydrology in three dimensions. These presentations provided important background for consideration of the workshop questions and the three presenters were valuable additions to the workgroups. Overall, the workshop participants included an appropriate mix of perspectives and scientific experience, as indicated by the range of opinion expressed in the small and large group discussions.

Participants engaged readily in the workgroup process, which involved rotating the workshop questions through a succession of workgroups. After brief explanation, this worked smoothly and the reporters provided detailed notes that provided much of the raw material for the workshop summary. USEPA staff also sat in on the workgroups, as non-participating observers, and took supplemental notes. Other observers from the public were permitted to view the morning presentations and the workgroup discussions, but were asked to remain silent. The one-day format with only brief breaks was a strain for participants and several noted their fatigue by the end of the day. Nevertheless, the participants all engaged actively in the plenary session at the end of the day and several stated afterward that they were pleased and encouraged by the workshop's outcome. Future workshops of this type should consider a longer schedule with additional breaks.

Based on communications before the workshop, and the past history of ongoing disagreement between some of the participants, I was encouraged by several indicators of a healthy working relationship, including:

- Willingness to share concerns openly with the facilitator before the workshop

- Willingness to suspend judgment where needed and participate in the workshop
- Careful listening and respectful discussion
- Ability to disagree without being disagreeable
- Willingness to acknowledge shifts in their own and others' positions on key issues
- Ability to combine different points of view into more integrated perspectives

Workshop outcomes

The workshop resulted in four outcomes that furnish a basis for further technical work on the issues addressed and for collaboration among the participants and the entities they are associated with.

Technical input

The workshop succeeded in producing substantial technical input addressing the workshop questions. While USEPA has not completed its review and synthesis of the workshop notes and summary, I believe that the presentations and discussion will enable USEPA to fulfill the three specific purposes of the workshop.

Improved clarity on key issues

My interactions with USEPA staff and workshop participants prior to the workshop highlighted important perceived differences of opinion about the meaning of terms such as "habitat" and "low salinity zone" and how these should be used in developing technical tools and policies for managing the Bay Delta.

Discussion during both the workgroup sessions and the final plenary session demonstrated broad agreement that the concept of habitat includes a number of physical and biological dimensions and that the LSZ captures only some of these. These dimensions will differ across species, life stages, and time. Habitat and LSZ are thus not synonymous, although salinity is certainly an important aspect of habitat. A more thorough understanding of habitat may therefore require species-by-species studies of the requirements and the mechanisms that affect these.

A corollary of a broader definition of habitat is that the LSZ is not the only cause of change in the estuarine ecosystem. In particular, historical ecology studies document the radical changes that have occurred in the Bay Delta's morphology and hydrology. This has the potential to affect assumptions about how closely existing processes can mimic natural condition (e.g., unimpaired flows), the design of studies to improve understanding of estuary function (e.g., resistance to salinity intrusion, and expectations of restoration potential.

Recommendations for new studies

Participants identified and generally agreed on the value of two types of new studies which were prompted in large part by information in three morning presentations. The first was efforts to integrate biological and physical models of estuarine processes, beginning with phytoplankton. The second was attempts to model the historical hydrology of the estuary. Both are described more completely in the section on Question 4: Modeling, above.

Improved environment for collaborative work

Several participants believed that the workshop outcomes, especially the general agreement on definition of key issues and recommendations for new modeling studies, were significant and opened the door to more productive discussion and collaborative efforts in the future. One such effort I heard suggested was the use of a joint fact finding process to engage parties with different perspectives on the management of the Bay Delta in a structured effort to identify a common basis of factual information and rigorously identify and attempt to resolve sources of disagreement.

Appendix 1: Workshop Planning Group

Members of the workshop planning group included:

• Bruce Herbold	US Environmental Protection Agency
• Tim Vendlinski	US Environmental Protection Agency
• Erin Foresman	US Environmental Protection Agency
• Thomas Jabusch	Aquatic Science Center
• Brock Bernstein	Consultant

Appendix 2: Modeling Estuarine Habitat in the Bay Delta

Modeling Estuarine Habitat in the Bay Delta

Unifying One and Three Dimensional Approaches to Modeling X2 and the Low Salinity Zone[1]

Estuarine Habitat and the Low Salinity Zone

Estuaries are coastal areas where rivers mix with seawater in semi-enclosed basins. The San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay Delta) is the largest estuary on the west coasts of North and South America, draining 40% of California's land area and encompassing the 478-square mile Bay, and the 1,153-square mile Delta[2]. Hydrodynamic processes ensue when light freshwater meets heavy seawater, and these processes both concentrate suspended solids and aquatic organisms, and comprise the *estuarine habitat* that supports multiple life stages for a diversity of fishes.

The location and extent of estuarine habitat fluctuates in response to river flows, ocean tides, weather, and geographic features (e.g., levees, the depth and breadth of stream channels, connectivity to adjacent wetlands). The *low salinity zone* (LSZ) occurs at the inland edge of estuarine habitat where average daily salinities range from 1 to 6 practical salinity units (psu)[3]. The turbidity of the LSZ results from the concentration of suspended solids, phytoplankton, and zooplankton, and these turbid conditions both shelter and provide food for young fish[4].

Anthropogenic Changes and Current Conditions in the Delta and Suisun Bay

Beginning in the 1850s, over 300,000 acres of tidal marshes in the Delta were diked, drained, and converted to agriculture[5]. Thus, the complex, shallow, and dendritic marshlands were replaced by simplified, deep, and barren channels (Figure 1). This hydrogeomorphic modification fragmented aquatic and terrestrial habitats, and decreased the quality and quantity of available estuarine habitat.

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[1] Drafted by Herbold and Vendlinski for the Technical Workshop on Estuarine Habitat (27 March 2012).

[2] The State of the Estuary: A Report on Conditions and Problems in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (SFEP, 1992).

[3] The UNESCO Practical Salinity Scale of 1978 (PSS78) is used to describe the concentration of dissolved salts in water and defines salinity in terms of a conductivity ratio. Salinity was formerly expressed in terms of parts per thousand (ppt) or by weight (parts per thousand or 0/00). That is, a salinity of 35 ppt meant 35 pounds of salt per 1,000 pounds of seawater. The salinity of freshwater is 0 psu and the salinity of the open ocean ranges from 32 to 37 psu. http://science.nasa.gov/glossary/practical-salinity-unit/

[4] Kimmerer, W. J., J. R. Burau, and W. A. Bennett. (1998). "Tidally oriented vertical migration and position maintenance of zooplankton in a temperate estuary." Limnology and Oceanography. 43(7): 1697-1709.

[5] Delta Ecosystem White Paper (October 2010), pages 4-5.

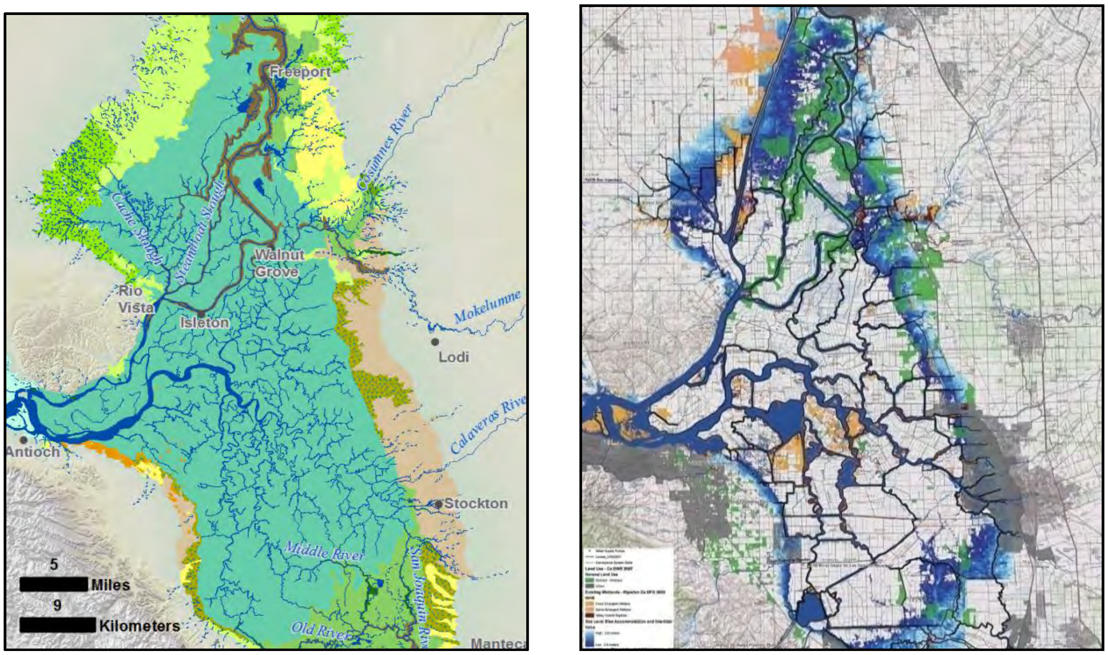

Figure 1: The Delta before and after diking and draining. The draft map of the Delta in the early 1880s on the left is courtesy of Grossinger and Whipple, SFEI (2012). The map of the post-modification, modern day Delta on the right was drawn from USBR-ESRI[6].

Since the year 2000, the position of the LSZ has been frequently fixed in the western Delta throughout the summer and fall until the first storms arrive. As a result, estuarine habitat is located in deep river channels for a large fraction of the year and exposed to a variety of stressors[7]. Fishes that follow the LSZ into this area face an increased risk of predation and entrainment resulting from a lack of cover and foraging habitat caused by the simplification of geographic features, and by the design and operation of water supply infrastructure. By contrast, when the LSZ occupies Suisun Bay, the estuarine habitat spreads out across the expansive shallows of Grizzly and Honker bays and into the large adjacent tidal marsh (Figure 2).

[6] USBR-ESRI: The California Delta—Ecosystem Restoration Targets and Levees at Risk.
In comparing their maps of the early 1880s Delta with the early 2000s Delta (the latter not pictured in this paper), Grossinger and Whipple found the maps revealed a reduction in historical tidal channel complexity with the damming of smaller waterways, channel widening, meander cuts, and straight connecting canals. The mapping done by USBR-ESRI led them to conclude that subsidence and anticipated sea level rise have limited restoration opportunities for aquatic and terrestrial habitats. This would apparently exclude the western Delta from consideration as a restoration target, however, USGS has demonstrated that subsided islands in the western Delta are restorable, and the subsidence reversible, through carbon farming with tule-based wetlands.

[7] For the purposes of this paper, the "western Delta" refers to the area around Sherman Island at the confluence of the Sacramento and San Joaquin rivers, river km 81 to 90.

While the form and function of the marsh have been greatly altered, the remnant wetlands still bear a resemblance to the habitat that once characterized both the Suisun Marsh and the western Delta. Most of the wetland acres within Suisun Marsh are managed for waterfowl, but there remain many dendritic sloughs lined with extensive fringing tidal wetlands. Suisun Marsh continues to shelter a number of aquatic species that are rarely found elsewhere in abundance.

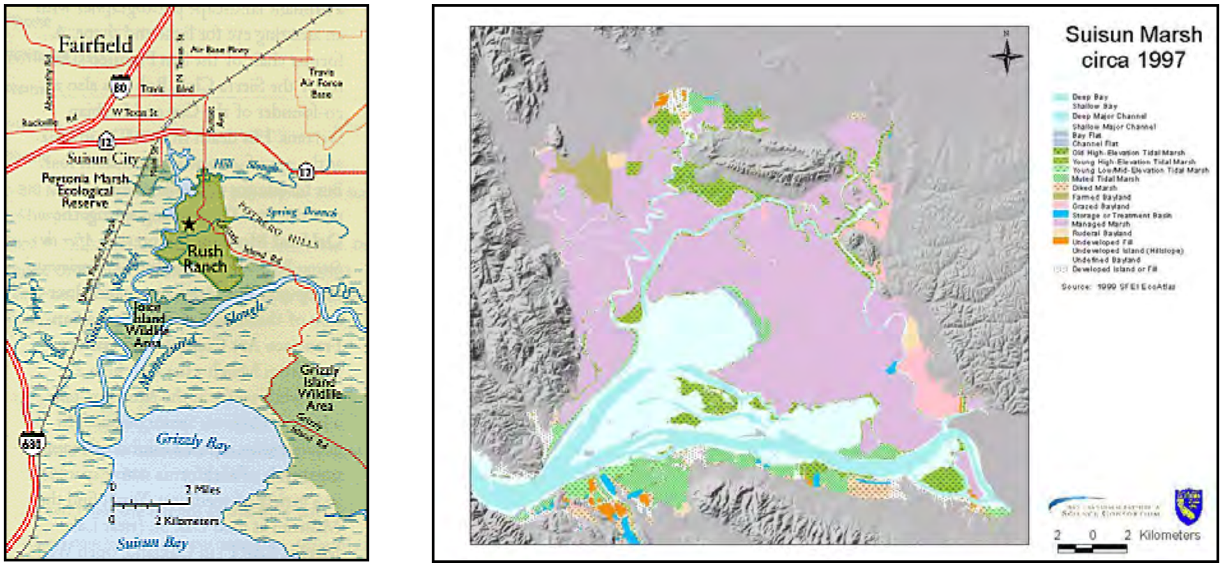

Figure 2: Suisun Bay and Marsh comprise the only area upstream of San Pablo Bay where shallow embayments are contiguous with significant, remnant patches of tidal marsh. Here, optimal estuarine habitat can be created by using Delta outflows to co-locate the LSZ with these geographic features. Map on left from Bay Nature (2001); map on right from CDFG's Suisun Marsh Atlas.

A number of species that often reside in the LSZ (e.g., delta smelt, longfin smelt, young striped bass), and a number of species that move in concert with the LSZ but are associated with higher salinities downstream (e.g., Pacific herring, starry flounder, and native shrimp species) show a greater abundance and survival when the LSZ shifts downstream from the western Delta and toward Suisun Bay. With the exception of delta smelt, the aforementioned species show a relatively straightforward, positive relationship between the westward locations of the springtime LSZ, and their greater survival as young fishes, or abundance as adults[8].

[8] Kimmerer, W. J. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series

A Brief History of X2

An *isohaline* is a line that connects all points of equal salinity in an estuary. Isohalines generally move in parallel with each other and in response to ocean tides, freshwater inflows, and, to some extent, atmospheric pressure. The abundance and survival of most of the aforementioned Bay Delta species are correlated with the location of the 2 ‰ (parts per thousand) salinity isohaline -- as measured in kilometers from the Golden Gate (Figure 3). In the early 1990s, scientists designated this parameter as *X2*[9], and since then, scientists have sought to understand the mechanisms behind the relationships of X2 with aquatic resources, and the changes in those relationships through time. Despite its statistical association with a variety of aquatic resources, the one-dimensional nature of the X2 parameter does not reveal the ecological processes that underlie those associations.

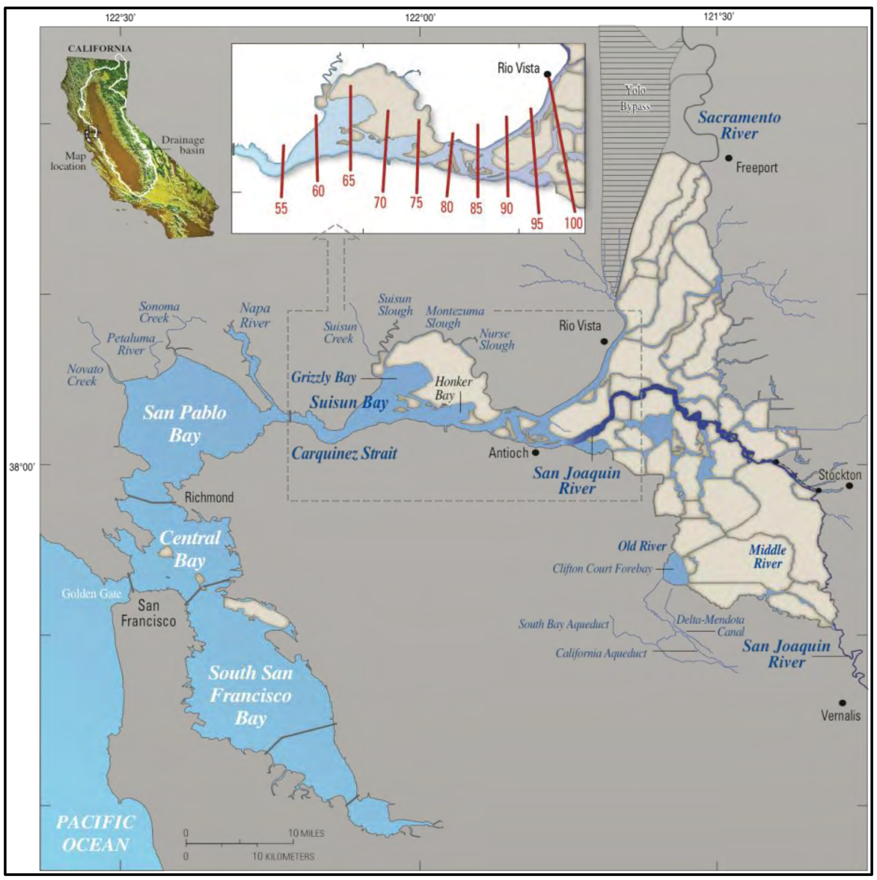

Figure 3. Isohaline positions (X2) measured at nominal distances (in kilometers) from the Golden Gate Bridge along the axis of the estuary. New ap by DeLio (2011) adapted from Jassby et al. (1995).

[9] Jassby et al. 1995 Isohaline Position as a Habitat Indicator for Estuarine Populations. Ecological Applications 5: 272-289.

Kimmerer and Monismith developed *the X2 model* to predict the location of X2 based on the preceding location of the isohaline and the present value of delta outflow[10], while Denton developed *the G model* to predict salinity at a particular location (intakes for drinking water) based on previous salinity conditions at that location and present delta outflow[11]. Today, X2 positions are interpolated from measurements of salinity at four locations in the Bay Delta and reported daily.

The Translation of X2 into Water Quality Standards

In 1995, the State Water Resources Control Board (State Board) adopted X2 as a water quality standard to help restore the relationship between springtime precipitation and the geographic location and extent of estuarine habitat. The regulatory requirements for this springtime (February through June) standard are indexed to monthly flows into reservoirs on the eight largest rivers draining into the Bay Delta[12]. This requires water managers to position X2 further downstream in wet months than in dry months either by increasing reservoir releases or, more commonly, decreasing exports from the Delta. Compliance is achieved by positioning X2 downstream of one of three locations: Roe Island (65 km), Chipps Island (74 km), or the confluence of the Sacramento and San Joaquin rivers (81 km). The State Board did not set standards for managing the location of X2 during other times of the year.

Following the State Board's implementation of the X2 standard under the 1995 Water Quality Control Plan, more characteristic springtime flows prevailed in the Delta, and migratory and resident fishes responded with modest yet significant increases in abundance. By 1999, increases in the population of delta smelt nearly achieved the criteria for delisting set forth in the federal recovery plan for native fishes in the Delta[13]. Moreover, populations were rebounding for both threadfin shad and longfin smelt, and populations of adult striped bass returned to levels not seen since the 1970s. However, beginning in the early 2000s, populations of delta smelt and other pelagic species experienced unexpected and dramatic declines, and this phenomenon became known as the *pelagic organism decline* (POD)[14] .

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[10] Wim Kimmerer (SFSU) and Stephen Monismith (Stanford University) developed the "X2 Model." Historical X2 is included in the DAYFLOW dataset, and calculated using this model.
[11] The "G Model" developed by Richard Denton of Contra Costa Water District.
[12] Eight largest rivers draining into the Bay Delta and their corresponding Reservoirs:
American River (Folsom Lake), Feather River (Lake Oroville), Merced River (Lake McClure),
Sacramento River (Lake Shasta), San Joaquin River (Millerton Lake), Stanislaus River (New Melones Reservoir),
Tuolumne River (Don Pedro Reservoir), and Yuba River (Engelbright Lake).
[13] FWS: Recovery Plan for the Sacramento/San Joaquin Delta Native Fishes (1996).
[14] Baxter, R., R. Breuer, L. Brown, M. Chotkowski, F. Feyrer, M. Gingras, B. Herbold, A. Mueller-Solger, M. Nobriga, T. Sommer, and K. Souza. 2008. Pelagic organism decline progress report: 2007 synthesis of results. Interagency Ecological Program for the San Francisco Estuary, Technical Report 227.

Modeling X2 and the Low Salinity Zone with 3D models

The LSZ is a three dimensional (3D) volume of estuarine habitat that changes its shape depending on its location in the Bay Delta. New models allow for the 3D characterization of the LSZ in terms of its average depth, width, and river kilometer, and can depict the dispersion of the LSZ over short time steps.

These models include the UnTRIM San Francisco Bay-Delta model (UnTRIM) that the Delta Modeling Associates adapted for use in the Bay Delta. Other models include the SUNTANS model developed by researchers at Stanford and U.C. Berkeley, and a public domain model being developed by DWR[15]. All of these models can, or have the potential to, characterize the hydrodynamics of the Bay Delta in a fine geographical scale and with small time steps that more closely mimic real world conditions than the aforementioned X2 and G models.

The following is not intended to be an endorsement of the UnTRIM model per se, but rather an exploration of the potential advantages of using a 3D approach toward characterizing the LSZ of the Bay Delta. EPA became aware of the UnTRIM model during the regulatory review of the proposed Sacramento Deep Water Ship Channel project proposed by the Corps of Engineers and the Port of West Sacramento.

The UnTRIM model was calibrated using data collected in the Bay Delta about water levels, flow, velocity, and salinity. The model provides a 3D hydrodynamic characterization of conditions from the Pacific Ocean eastward through the entire Sacramento-San Joaquin Delta. Predicted water levels were compared to observed water levels at monitoring stations administered by DWR and NOAA in San Francisco Bay, and those administered by DWR and USGS in the Delta. Large grid cells were used to characterize the Pacific Ocean, and these cells gradually transition to finer grid resolution for the small channels of the Delta (Figure 4). This approach allows for detailed analysis of local hydrodynamics, while still incorporating the overall hydrodynamics of the larger estuary in a single model.

[15] Stanford Unstructured Nonhydrostatic Terrain-following Adaptive Navier-Stokes Simulator (SUNTANS)

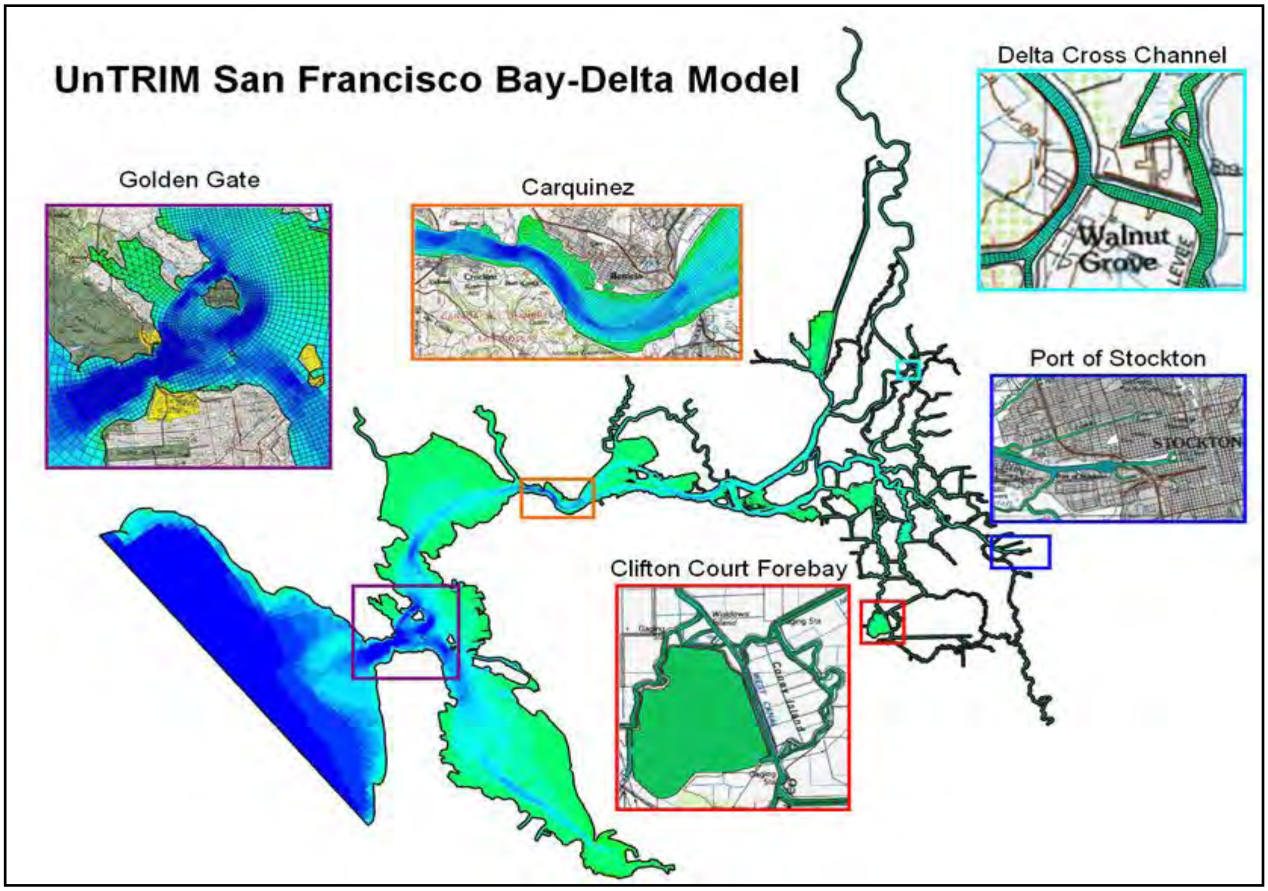


Figure 4. The domain and samples of the computational grid for the UnTRIM model.

Characterizing the LSZ in relation to X2 using the UnTRIM Model

In the figures below, the volumetric UnTRIM model was used to characterize: (i) the areal extent of estuarine habitat (in hectares) corresponding to the regulatory compliance points established for X2 under the 1995 Water Quality Control Plan; and (ii) the percentage of time per day the LSZ resides in a given location of the Bay Delta[16]. Presenting the data in this way unifies the 1D approach employed by the State Board since 1995 to manage the location of X2, and the 3D approach (depth, width, and river kilometer) now available to characterize the position and volume of the LSZ.

[16] The ability of the UnTRIM model to account for time means it can be used to model a 4th dimension of estuarine hydrodynamics.

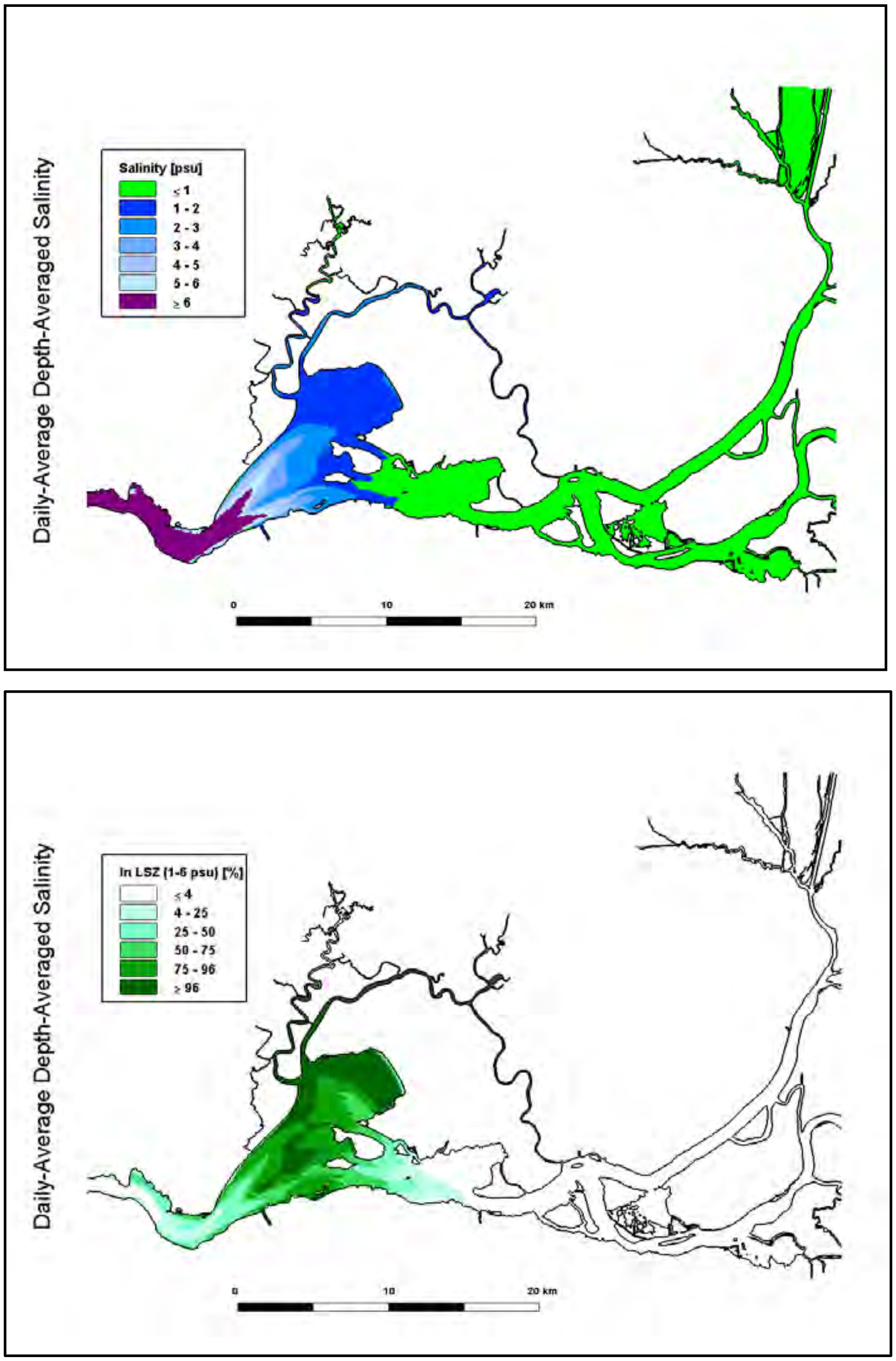


Figure 5a & 5b. X2 = 65 km (downstream of Roe Island). The upper figure shows parts of the LSZ in shades of blue from 1-6 psu stretching across 7,704 hectares and the broadest regions of Suisun Bay adjacent to Suisun Marsh. The lower figure shows the percentage of day that the LSZ occupies different areas of the Suisun Bay and Marsh.

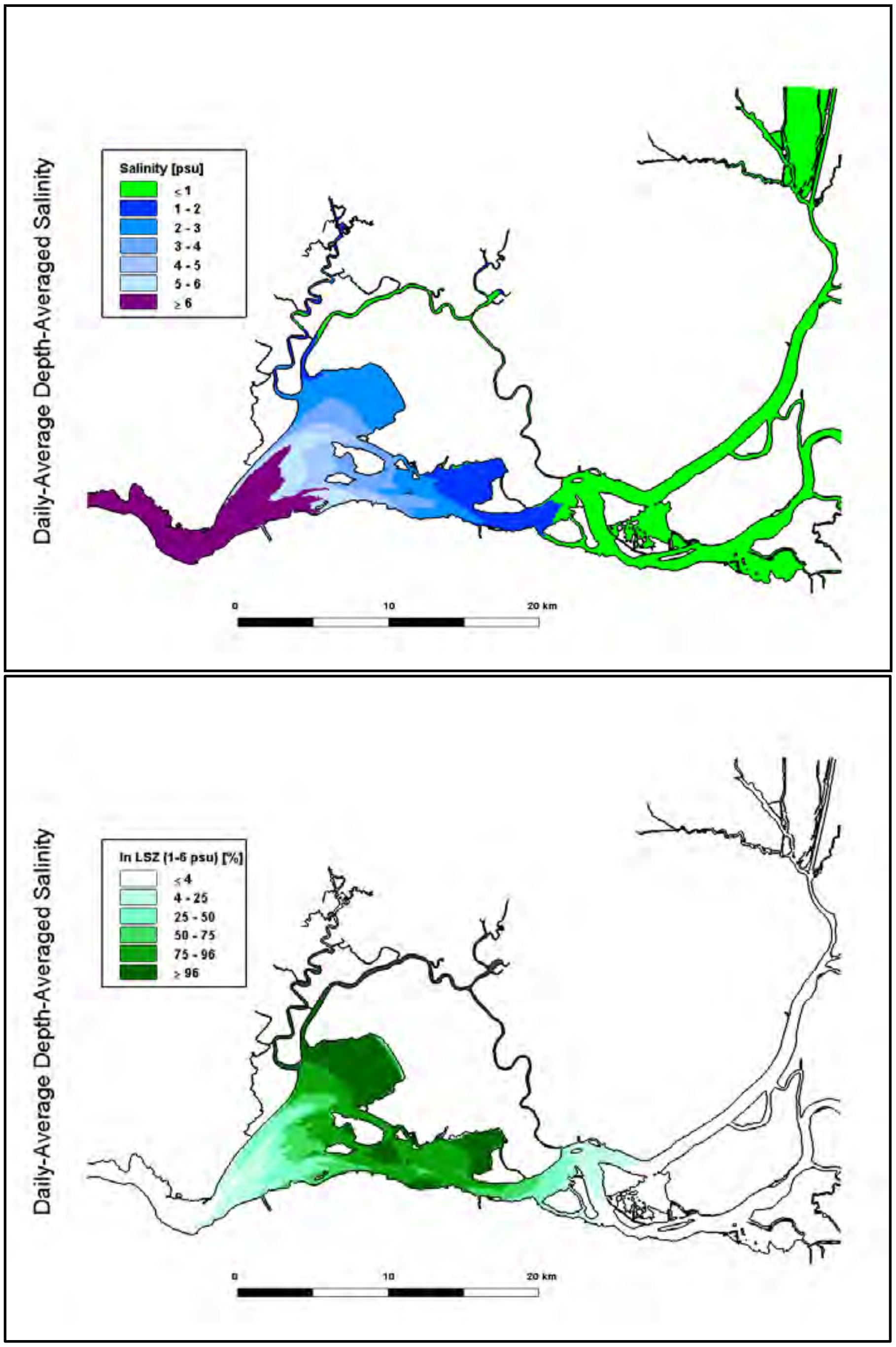
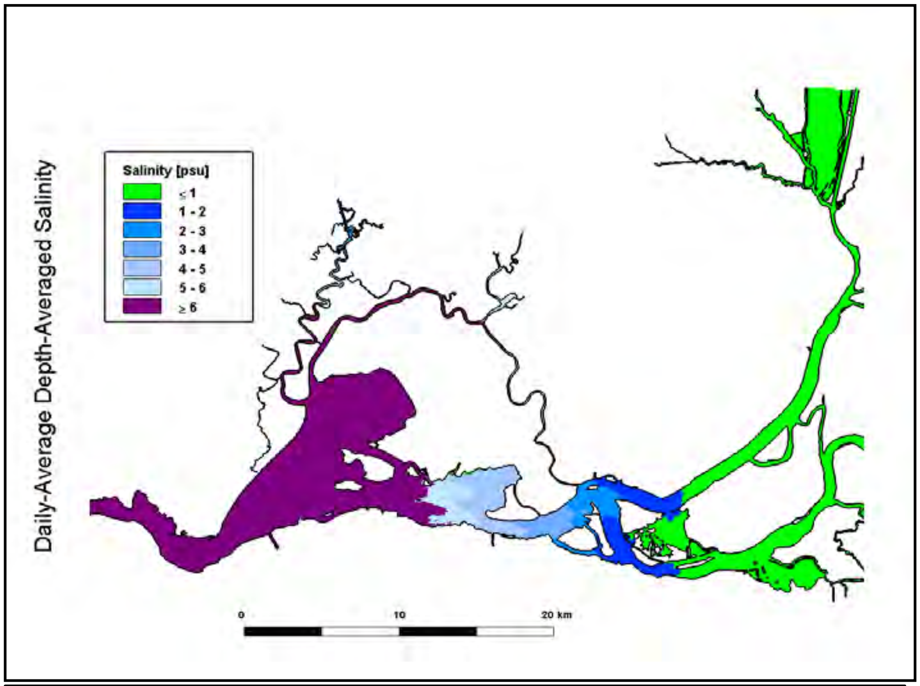


Figure 6a & 6b. X2 = 74 km (at Chipps Island). The upper figure shows the LSZ covering 9,140 hectares. While the total areal extent of estuarine habitat is greater than in Figure 5a, the benefits derived from this greater expanse of the LSZ might be offset by the occurrence of higher salinities across Grizzly Bay and the squeezing of lower salinities into Honker Bay. The lower figure shows the percentage of day that the LSZ occupies different areas.



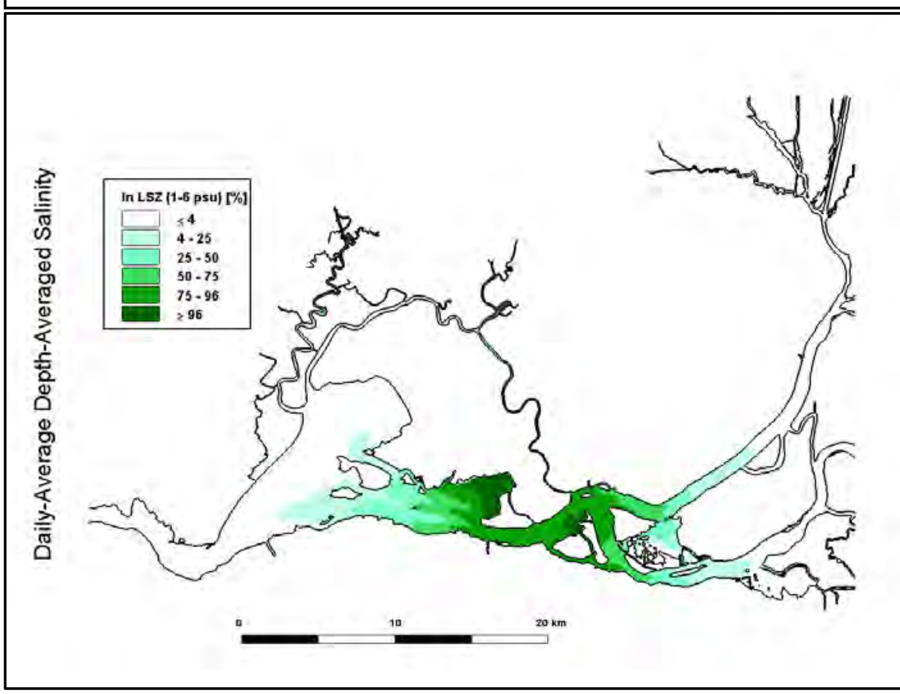


Figure 7a & 7b. X2 = 81 km (at the confluence of the Sacramento and San Joaquin rivers). The upper figure shows the LSZ being compressed into 4,914 hectares within the relatively deep channels of the western Delta. The lower figure shows percentage of day that the LSZ occupies different areas.

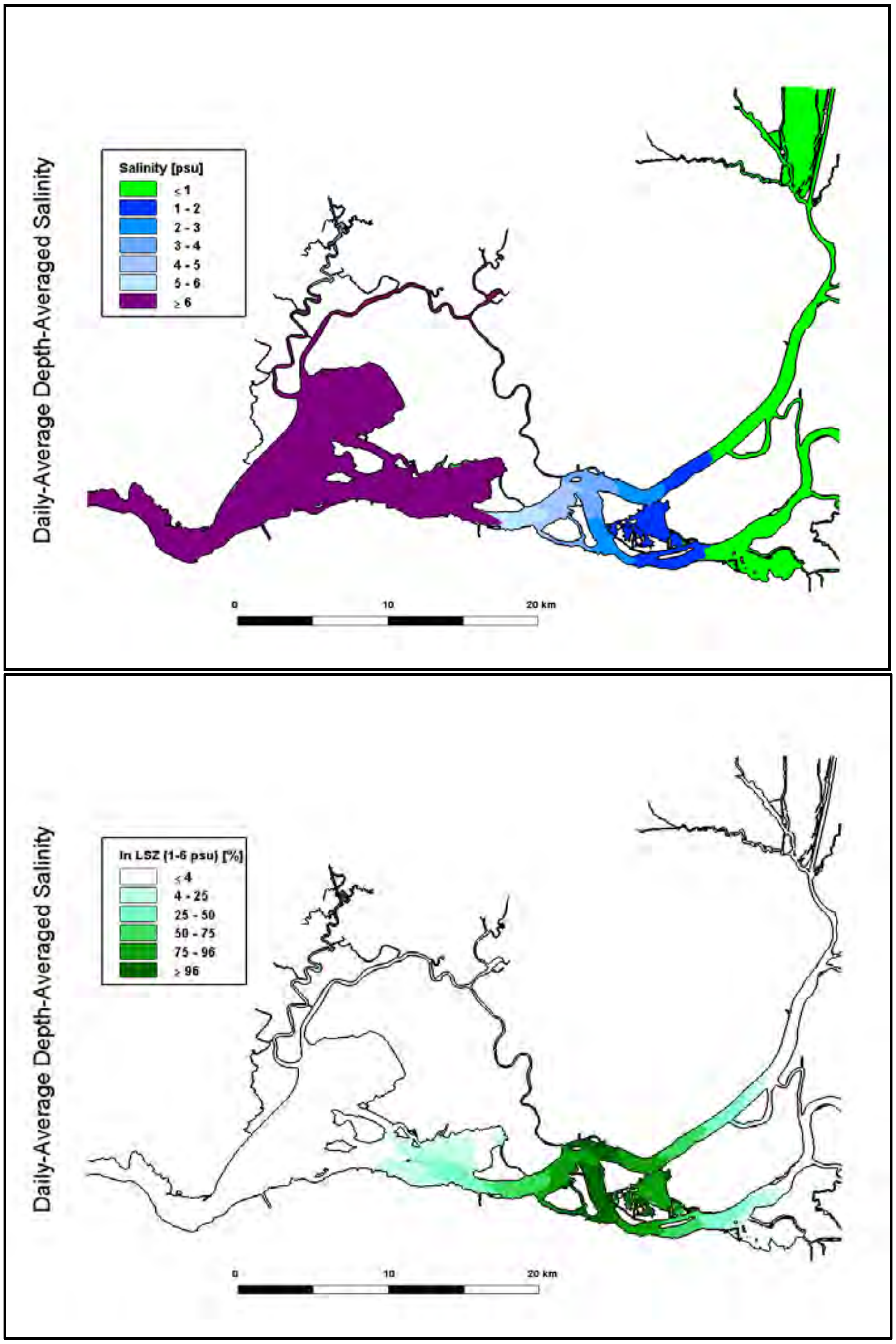


Figure 8a & 8b. X2 = 85 km. The upper figure shows the LSZ being positioned mostly between Antioch and Pittsburg where the areal extent of estuarine habitat drops to 4,262 hectares, and important connections to Suisun Bay and Marsh have nearly been lost. The lower figure shows the percentage of day that the LSZ occupies different areas.

UnTRIM depictions of Depth, Area, and Volume of the LSZ in relation to X2

The diverse geometry of the upper San Francisco Estuary produces different physical characteristics of the LSZ at different locations. The predictability of the relationship between X2 and the physical characteristics of the LSZ is markedly different upstream and downstream of Carquinez Strait.

The area of the LSZ modeled by UnTRIM shows a strong relationship with X2, due to the distribution of shallow habitats along the axis of the estuary. However, this relationship is much more consistent east of Carquinez Strait (X2 > 50) than westward (Figure 9). The relationship of average LSZ <u>depth</u> with X2 is almost perfectly inverse to that of the LSZ <u>area</u> (Figure 10).

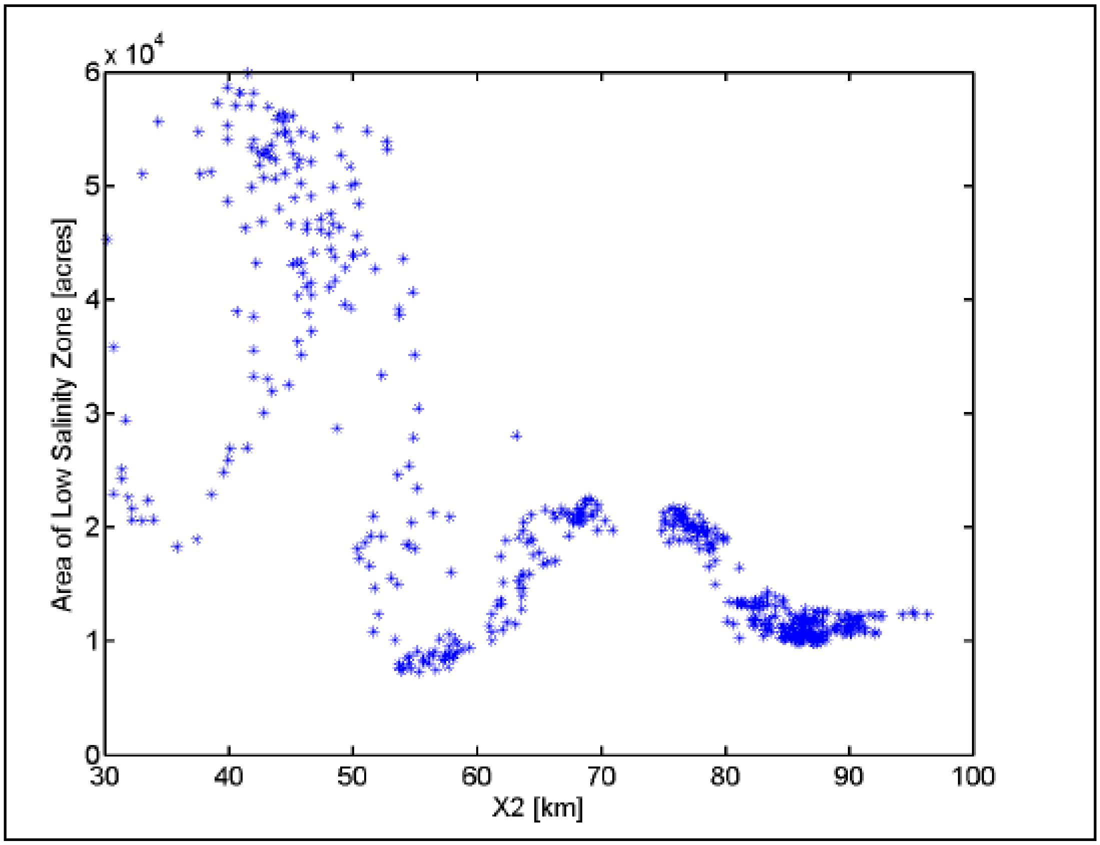


Figure 9. Average acreage of the Low Salinity Zone as a function of X2 using 549 days of data spanning 1 April 1994 to 1 October 1995.

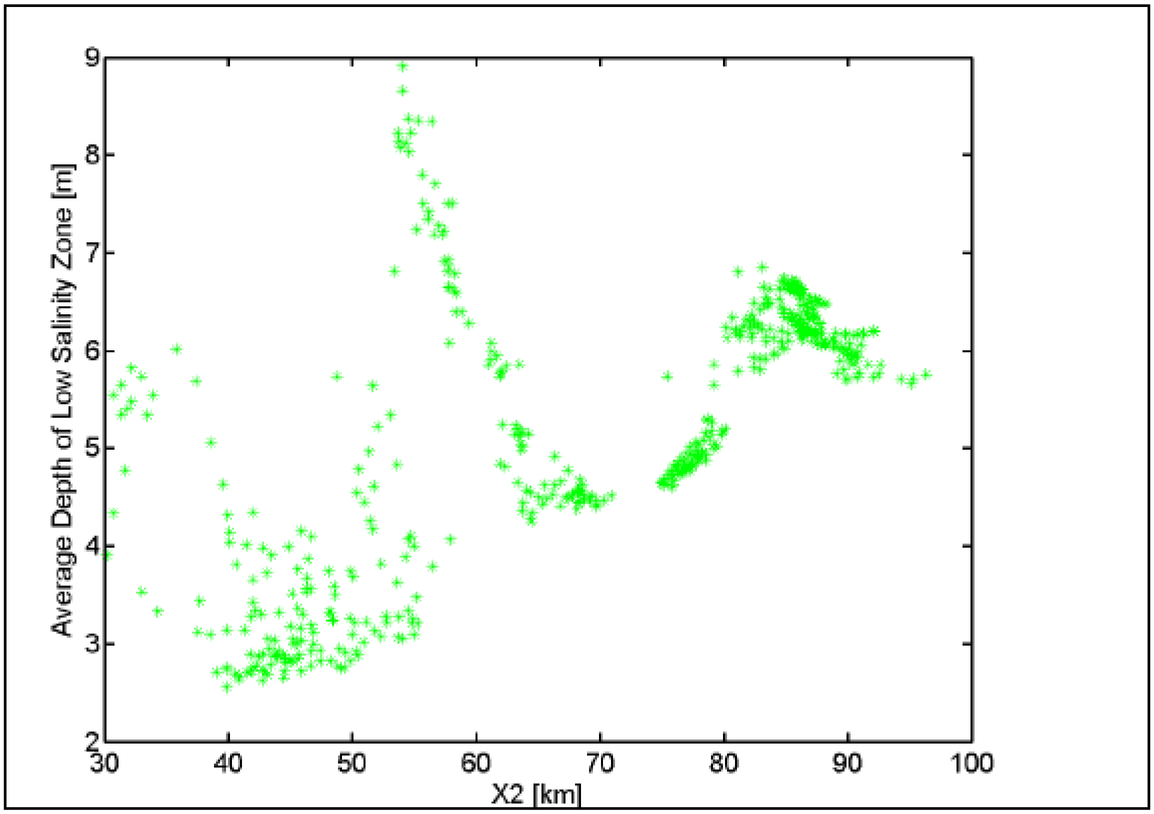
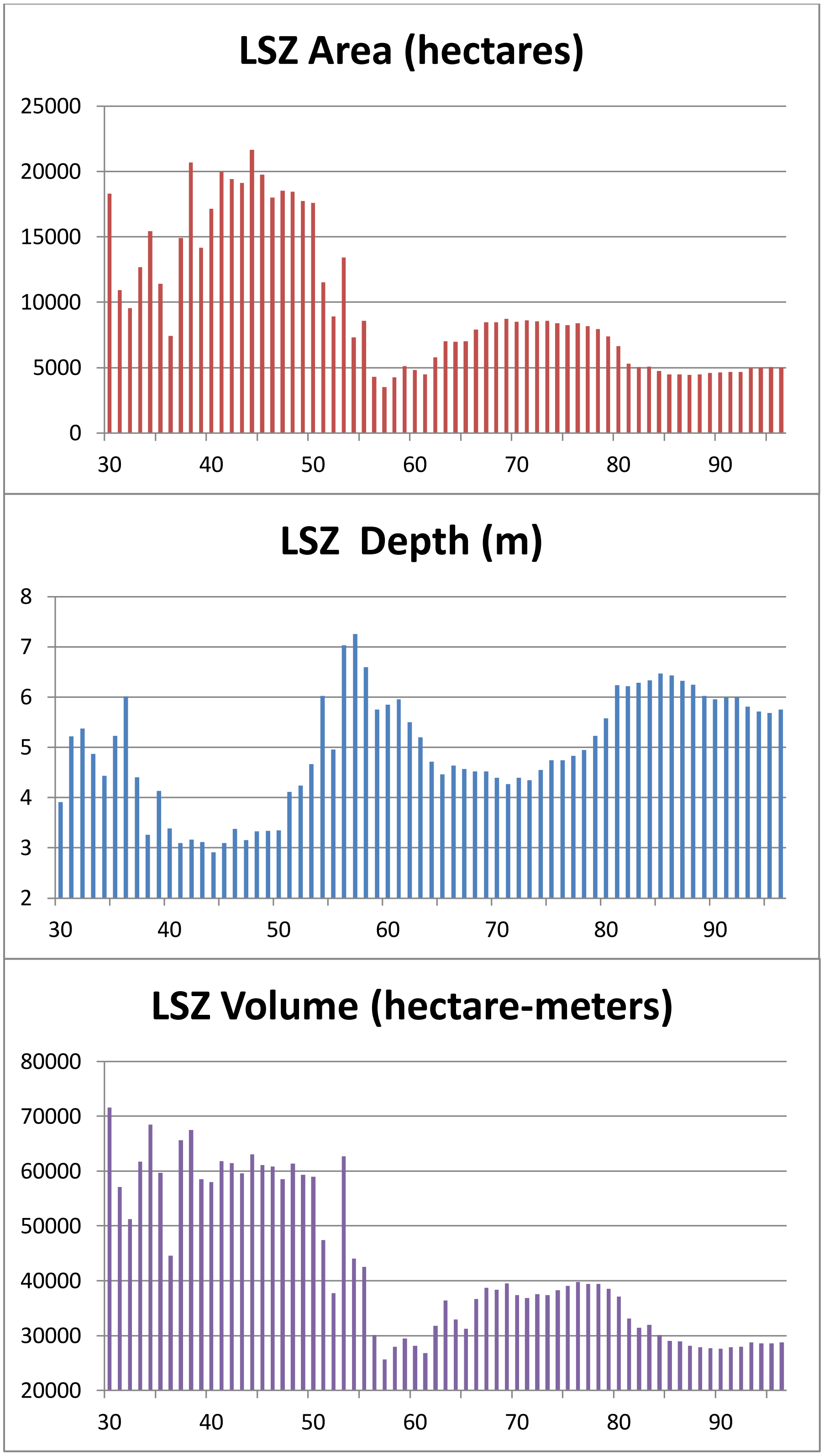


Figure 10. Average depth of the Low Salinity Zone as a function of X2 using 549 days of data spanning 1 April 1994 to 1 October 1995.

The volume of the LSZ shows the least relationship with X2 due to the opposing nature of depth versus areal extent (Figures 11a, 11b, and 11c). Many ecological processes within estuarine habitat depend on the depth, area, and volume of the LSZ and its proximity to various habitats and stressors, which 3D models can fairly accurately and precisely predict. Deeper areas support gravitational circulation, shallow areas expose more of the water column to the photic zone, etc. Unlike the one-dimensional X2 approach, the 3D models lend themselves to the construction of predictive models of ecological processes.



Figures 11a, 11b & 11c. Average area, depth, and volume of the LSZ at 1 km changes in X2.

Appendix 3: Review of Scientific Papers and Summary of Key Findings

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DRAFT

Review of Scientific Papers and Summary of Key Findings

For the ASC-EPA Technical Workshop on
Estuarine Habitat in the Bay Delta Estuary

Prepared for
U.S. Environmental Protection Agency
March 2012

Thomas Jabusch
Aquatic Science Center

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Building a Common Library of Scientific Papers

This document summarizes the key findings of selected technical papers on X2, the low salinity zone, and the ecological community of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay Delta Estuary). The Aquatic Science Center (ASC) prepared the summary to support the technical workshop on estuarine habitat being staged in Sacramento on 27 March 2012 by ASC and EPA. This summary is accompanied by a common library of online scientific papers that workshop participants will be able to access before, during, and after the workshop. ASC analyzed papers in this library to identify common themes, key points of agreement and disagreement (and reasons thereof), and uncertainties.

The common library was built through a relatively informal process. As a starting point, Dr. Bruce Herbold offered an initial list of thirty-six (36) "essential" LSZ/X2 papers produced since 1995. This became known as the "long-list" of papers that provided a useful reference tool to subsequent reviewers of the list. Based on the long-list, Dr. Wim Kimmerer kindly suggested a shorter, more manageable set of papers, and this became known as the "short list." Dr. Kimmerer used the following criteria for selecting a paper for the short list: the paper (1) applies in particular to the low-salinity zone, or to species resident there; and (2) either provides a good overview of the habitat, or provides new looks at particular aspects of that habitat.

Drs. Anke Mueller-Solger and Matt Nobriga graciously reviewed both lists and added their own recommendations. Each scientist arrived at a slightly different list of essential papers, and all agreed that the task was difficult and depended upon the selection criteria for inclusion. Given time constraints, prospective workshop participants were not surveyed about the selection criteria, and ASC and EPA were willing to accept the basic criteria established by Dr. Kimmerer and the collective, best professional judgment of Drs. Herbold, Mueller-Solger, and Nobriga. The final list of 23 papers provided here represents a hybrid of the "desert island" lists that were provided by each expert. The workshop planning team[17] accepted these papers as those most likely to garner the greatest acceptance among workshop participants for their characterization of ecological processes and hydrodynamics pertaining to X2 and the low salinity zone.

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[17] Members of the Planning Team for the Estuarine Workshop

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Summary of Key Findings

There are well-accepted statistical relationships between the abundance and survival of fishes and other estuarine species with the location of the low salinity zone (LSZ), as represented by X2 (the 2% bottom salinity position). However, there is a need to more extensively study causal relationships among X2, estuarine habitat quality, and fish populations.

Agreements

The following statements represent general consensus of the science community, as represented in the peer-reviewed literature pertaining to the LSZ or X2:

Habitat

Abundance of Zooplankton and Young Fishes is Centered Near or Slightly Upstream of the LSZ. Bennett et al. (2002), Jassby et al. (1995), Kimmerer et al. (2002), Moyle et al. (1992).

Low Salinity Habitat Distributed Over Shoal Areas Is More Productive and Provides Better Rearing Conditions Than Habitat Confined to Deeper Channels. Overall, the historical sampling record indicates that delta smelt have remained several fold more abundant in northern Suisun Bay and Suisun Marsh channels than in southern Suisun Bay and the Delta. There also appears to be a link between the recruitment success for delta smelt and the availability of shallow-water habitats rather than the amount of freshwater outflow alone (as indexed by X2). Bennett (2005), Bennett et al. (2002), Moyle et al. (1992).

Delta Smelt Habitat Extent. Delta smelt is endemic to the estuary; habitat extends from the tidal freshwater reaches of the Delta seaward to about 19 psu salinity at water temperatures lower than 25°C. Bennett (2005).

Habitat for Northern Anchovy Is Negatively Related to X2. When the Asian clam *Corbula amurensis* invaded the San Francisco Estuary in 1986, the distribution of northern anchovy (*Engraulis mordax*), the most common fish in the estuary, shifted toward higher salinity, reducing summer abundance in the LSZ by 94%. The response of the anchovy to the arrival of *Corbula* was rapid, manifested in a sharp decline in summer abundance from 1986 to 1987. The resulting shift in the anchovy's spatial distribution in the estuary appears to have been a direct behavioral response to reduced food (i.e., reduction in overall biomass and replacement of preferred zooplankton species by invasives, as indicated by carbon biomass estimates). Although the abundance of northern anchovy has declined in the low salinity zone, it still dominates the biomass of fish in the more saline reaches of the estuary. The bulk of the anchovy population even before the decline was at high salinity: 95% of the catch before 1987 occurred at salinities greater than 10%.

The disappearance of the northern anchovy from the LSZ may have allowed more successful foraging of remaining species, especially delta smelt and longfin smelt. Northern anchovy is a filter feeder, food density-dependent feeder and thus may be more sensitive to changes in the abundance of their prey than smelt, which are "picking type" of feeders whose feeding success is more of a density independent, or density vague process.

Bennett (2005), Kimmerer (2006).

Fish Populations

The Pelagic Organism Decline (POD): Populations of Four Pelagic Fishes Suddenly Declined in the Early 2000s. Change point models detected step declines in abundances of delta smelt, longfin smelt, striped bass, and threadfin shad in the early 2000s, with a likely common decline in 2002. However, no single factor emerged to explain the POD (see Uncertainties), which is now believed to be the result of multiple effects. Abiotic habitat factors relate directly and indirectly to the declining fish abundances. The conclusion is based on univariate and multivariate analyses of the effects of abiotic habitat variables, in particular X2 and water clarity. Abiotic habitat factors can affect fish by directly increasing or decreasing the extent of their physical habitat and indirectly by impacting their prey or predators. Bennett (2005), Mac Nally et al. (2010), Thomson et al. (2011).

Delta Smelt and Striped Bass Are More Abundant in More Turbid Waters. Based on generalized additive modeling results, the predicted occurrence of delta smelt and striped bass decreased as Secchi depth increased. Feyrer et al. (2007).

Young Fishes And Zooplankton Can Actively Maintain Position Within the LSZ. Young fishes migrated vertically and maintained position in the LSZ, switching between two strategies depending on freshwater flow and longitudinal position of the LSZ. Zooplankton in the LSZ also migrate vertically with the tides to maintain position, but there are differences among years and between taxa. Bennett et al. (2002), Kimmerer et al. (1998), Kimmerer et al. (2002).

Delta Smelt Is at Risk of Extinction. Limited distribution, short life span, low reproductive capacity, as well as relatively strict abiotic habitat and feeding requirements, are indications that delta smelt is at catastrophic risk in a fluctuating environment. A small percentage (<10%) lives two years and may have an important influence on population dynamics by augmenting spawning success after years of poor recruitment. Bennett (2005).

Flow Response

The Abundance of Several Common Species of Fish Varies Positively With Flow Entering the Estuary, as Indexed by X2. Based on data collected through 1992, Jassby et al. (1995) presented simple and significant statistical relationships of X2 with annual measures of phytoplankton-derived detritus from river loading; mollusks; mysids (*Neomysis mercedis*); bay shrimp (*Crangon franciscorum*); larval fish survival; and the abundance of longfin smelt (planktivorous), striped bass (piscivorous), and starry flounder (bottom-foraging). The abundance of most of these fish and the shrimp species is elevated in years when mean spring and early summer (April – July) X2 locations are moved seaward (closer to the Golden Gate) by high Delta outflows. The starry flounder abundance index responds to spring X2 in the previous year.

There are also notable exceptions. For example, delta smelt abundance does not correspond to X2. However, Bennett (2005) notes that the abundance of delta smelt is elevated only in years when the low salinity zone is located in Suisun Bay.

Adding 7 to 8 yr of post-*Corbula* data (based on availability) to those previously analyzed by Jassby et al. (1995), Kimmerer (2002) found that most of the species that were responsive to flow before *Corbula*'s arrival continue to have statistically demonstrable linkages between abundance or early life stage survival and X2 position. Kimmerer's analyses confirmed that all of the fish and shrimp, except delta smelt, had negative relationships with X2, indicating higher abundance at high flow. Two of them, starry flounder and longfin smelt, had negative relationships with X2 with no significant change in slope before and after 1987 but with lower intercepts after 1987, indicating 4-fold declines in overall abundances after the arrival of *Corbula*. The bay shrimp *Crangon franciscorum* had a significant relationship with X2 that had not appeared to change since 1988, although both the lowest and highest residuals around the X2 trend line were observed after 1988, indicating a possible transient response either to the change in the food web or to the extended drought from 1985 to 1992. Exceptions to this overall trend of continuity were the response of delta smelt and the mysid shrimp *Neomysis mercedis*. The latter was previously abundant in the LSZ in summer but declined about 50-fold after 1987. The response of *N. mercedis* to X2 changed significantly between the two periods, with a negative slope through 1987 (higher at high flow) and a steep positive slope thereafter (higher at low flow). Regressions on delta smelt abundance index data from 1975 – 1999 for two time periods (1975 – 1981 and 1981 – 1999) showed a positive relationship with X2 during the period up to 1981 and a negative but non-significant relationship from 1982 on.

Although X2 is not equivalent to flow, it still reflects the large interannual variability in river flow. Daily, monthly, and seasonal time series regressions demonstrate strong relationships between X2 and Delta outflow. $X2 \sim Q^{1/7}$, based on more than 20 years of data in which flow varies by a factor of approximately 200.

Jassby et al. (1995), Kimmerer (2002), Monismith et al. (2002), Moyle et al. (1992), Nobriga et al. (2008).

Organic Carbon Supply Increases With Flow. The supply rate of organic carbon to the Estuary increases with increasing freshwater flow, mainly because of river-borne inputs. However, much of the organic carbon in wet years is wood and thus less bioactive. Herbold (pers. comm.), Jassby et al. (1995).

Foodweb

Lack of Phytoplankton Blooms in the Upper Estuary. In the two most recent decades, phytoplankton blooms have been rare in the Estuary although nutrient concentrations are high. Blooms in the estuary were common in earlier years, despite higher turbidity. Alpine and Cloern (1992), Dugdale et al. (2007).

***Corbula* Caused a Major Change in the Food Web.** Chlorophyll a and several species of zooplankton (including mysids and some copepods) declined markedly after 1987. Mysids declined by about half and declines in some copepod species were accompanied by increases in other, introduced species. These introduced species are of lower nutritional value (e.g. omega fatty acid content). The now dominant exotic copepod, *Limnoithona tetraspina*, is also much smaller than the species it replaced, requiring planktivores to "work harder" to capture equivalent quantities of food. Bennett (2005), Herbold (pers. comm.), Kimmerer (2002), Kimmerer (2006).

Low Salinity Zone

The Salinity Field Embodies Information Not Directly Or Solely Related to the Chemical Properties of Water. The amount of freshwater flow into the Estuary is reflected in the salinity distribution, which in turn may determine the geographic location of estuarine turbidity maxima, entrapment phenomena, or null zones. For example, variation in gravitational circulation at a longer time scale may occur due to movement of the LSZ in response to variation in freshwater flow. Jassby et al. (1995), Peterson et al. (1975).

The LSZ Forms Multiple Turbidity Maxima of Various Origins. In the varying bathymetry of northern San Francisco Bay, the LSZ can move between shallow and deep water, altering the propensity for gravitational circulation to occur and producing multiple turbidity maxima that are positioned by bottom topography instead of salinity. Gravitational circulation is dependent on depth and more frequently observed in the deeper water column of Carquinez Strait, compared to shallower areas. Bennett et al. (2002), Kimmerer et al. (2002), Schoellhamer (2001).

Habitat Models

Habitat Volume is Highly Correlated With Surface Area. Kimmerer et al. (2009) simulated habitat volume using the TRIM3D hydrodynamic model and found that slopes of habitat volume vs. X2 were highly correlated with slopes of habitat area vs. X2 (r^2 = 0.97). Feyrer et al. (2011), Kimmerer et al. (2009).

Disagreements

Habitat

Best Method for Examining and Predicting Habitat Use. Both Kimmerer et al. (2009) and Feyrer et al. (2011) employed General Additive Modeling (GAM) to predict habitat use by estuarine fish. Kimmerer et al. (2009) employed habitat curves based on catch per trawl, because they were usually closer to the underlying fish distributions than those based on frequency of occurrence, which they argue tended to be extremely skewed. Feyrer et al (2011) chose to model frequency of occurrence rather than catch per trawl, as they argue, to minimize the possible influence of outliers and bias associated with long-term abundance declines. Feyrer et al. (2011), Kimmerer et al. (2009).

Flow Response

Fish Responses to X2 Remain a Topic of Debate. Kimmerer et al. (2009) observed that abundance –springtime X2 relationships correspond with habitat volume-springtime X2 relationships for striped bass, but not for delta smelt, longfin smelt, or in fact, most of the other species examined. These findings imply that increasing quantity of habitat, as defined by salinity, cannot explain the X2 relationships for most of the species and suggests that other mechanisms may be more or equally important. For example, the abundance index of longfin smelt varied by about two orders of magnitude over the range of X2 values, whereas the observed modest slope of habitat to X2 would allow for only about a twofold variation in abundance index over that X2 range. Kimmerer et al. (2009) conclude that increases in quantity of habitat may contribute to longfin smelt's strong X2 relationship, but that the mechanism chiefly responsible for it remains unknown.

Feyrer et al. and Nobriga et al. (2008) suggest that for delta smelt, the relationship between X2 and abundance is not apparent, because the delta smelt population may be responding to spatial scales smaller than other, more widely distributed species. They also conclude that delta smelt respond to regional salinity patterns through time, and specifically to conditions that occur seasonally in summer and fall. They imply that the springtime X2 (January – June) used by Kimmerer et al. (2009) and Bennett (2005) may not be expected to predict the abundance of delta smelt, due to the fact that these fish, due to other limiting factors, may not arrive in the LSZ until late spring or early summer. Nobriga et al. (2008) found that salinity predicted delta smelt occurrence in summer in three distinct geographic regions (Suisun Bay, Sacramento-San Joaquin River confluence, and San Joaquin Delta) that had similar long-term trends in delta smelt capture probabilities. Through generalized additive modeling, Feyrer et al. (2007) concluded that the combined effects of fall stock abundance and water quality (i.e., salinity and water clarity), predicted recruitment abundance in the following summer, at least during the past two decades, when food availability was severely reduced by *Corbula*.

Bennett (2005), Feyrer et al. (2007), Jassby et al. (1995), Kimmerer (2002), Kimmerer et al. (2009), Nobriga et al. (2008).

Foodweb

Decline in Phytoplankton Biomass. The downward trend in phytoplankton biomass over the last few decades is combined with "demographic" changes in the phytoplankton community from large diatoms to flagellates, blue-green algae, and smaller species of diatoms. The drivers of the algal trends are still being debated. The large decline in phytoplankton biomass (as measured by chlorophyll a) in Suisun Bay occurred mostly after the introduction of *Corbula* in 1986. The overall decline in phytoplankton biomass came hand in hand with a decline in the proportion of diatoms. Several other drivers are thought to play a role in the observed changes to the algal community. Among them are increased ammonia loadings, water diversions, and a reduction in phosphorus loadings. Earlier observations that phytoplankton has rebounded in the Delta in the late 90s seem to be confounded by more recent data indicating a continuation of the long-term decline. Baxter et al. (2010), Bennett and Moyle (1996), Brown (2009), Dugdale et al. (2007), Jassby (2008), Jassby et al. (2002), Kimmerer (2002), Kimmerer (2005), Van Nieuwenhuyse (2007), Winder & Jassby (2010).

Decline in Productivity. Since the mid-1970s, the upper Estuary had experienced declines in phytoplankton biomass, zooplankton abundance, and fish populations. Whether or not these declines are driven by declines in primary productivity and consecutive trophic changes remains a topic of debate. For example, based on the findings by Dugdale et al. (2007), ammonium (NH_4) may decrease primary productivity by inhibiting algal growth (Dugdale et al. 2007). Others hypothesize that NH_4 may be shifting primary productivity to *Microcystis*, blue-green algae of less nutritional value (Glibert 2010). On the other hand, clams are believed to capture and largely redirect productivity from the pelagic to the benthic foodweb, not necessarily resulting in a decline in primary productivity overall (Kimmerer 2002). And then again, extensive grazing by clams may deplete populations of phytoplankton to the point where primary productivity is getting reduced. However, the main conclusion drawn by Kimmerer (2002) was that the decrease in the abundance of phyto- and zooplankton was not associated with trends in fish, thus implying that fish declines are not driven by trophic changes. Dugdale et al. (2007), Glibert (2010), Kimmerer (2002)

Uncertainties

Habitat

Our Picture of Abiotic Habitat Condition Is Limited. Salinity, water clarity, and temperature are important water quality variables but don't fully define abiotic habitat. Additional information is needed to better define the mechanisms that mediate the effects of water quality variables on aquatic organisms. This also requires a more complete understanding of how the direct effects of water exports interact with the indirect effect of affecting abiotic conditions and the food web. Bennett (2005), Feyrer et al. (2007); Jassby et al. (1995), Kimmerer (2002), Kimmerer et al. (2009), Nobriga et al. (2008), Mac Nally et al. (2010).

Future Habitat Trends Are Uncertain. There is high uncertainty about future trends in factors that are likely to influence habitat suitability, such as future precipitation, sea level rise, additional invasive species, catastrophic natural events, or future policy directions. Bennett (2005), Feyrer et al. (2007), Nobriga et al. (2008).

Causal Relationships Between the Hydrodynamics of the LSZ and the Abundance and Distribution of Young Fishes Remain Largely Unresolved. Jassby et al. (1995), Nobriga et al. (2008).

Data Are Limited on Many Potential Factors Affecting Habitat Suitability. Many potential factors may affect habitat suitability, including food density, entrainment risk, predation risk, or exposure to contaminants. Data on such factors are limited. Interactions between abiotic and biotic habitat components can affect vital rates (per capita birth, death, fecundity) and exert density-dependent effects on population dynamics, although such relationships are currently poorly understood. Bennett (2005), Feyrer et al. (2007), Feyrer et al. (2011), Mac Nally (2010).

Macrophyte Proliferation May Adversely Affect Pelagic Fishes. The invasion of aquatic macrophytes has already substantially changed near-shore fish assemblages and may also have restricted pelagic fish distributions. In particular, the invasive Brazilian waterweed (*Egeria densa*) increases water clarity by trapping suspended sediments, thus negatively affecting native and desirable pelagic fishes. Furthermore, piscivorous yearling striped are typically found in shallower channels that are now subject to increasing density of *Egeria* beds. This may have implications on the result of abundance and possibly changes in available prey items. The association with *Egeria* beds may also skew abundance indices, since fish in shallow water with dense vegetation are less susceptible to being caught in the Fall Midwater Trawl on which these estimates are based. Feyrer et al. (2007), Herbold (pers. comm.), Nobriga et al. (2005, 2008).

Fish Populations

Vertical and Horizontal Distribution Patterns of Zooplankton and Fishes Are Not Fully Understood. There are differences among years and variability among taxa in the tidal movements of zooplankton and fishes in the LSZ that are not fully explained. The migratory behavior of copepods is not consistent with, but also not responsive to, changes in freshwater flow, salinity, or stratification. In the Suisun Bay ship channel, most fishes and zooplankton appeared to undergo tidal vertical migrations, occurring near the surface during flood tides and at depth on ebbs. However, in Suisun Cut some fishes, including delta smelt, appeared to undergo reverse diel migrations, remaining near the surface during the day and at depth during the night. Delta smelt post-larvae in freshwater portions of the Sacramento and San Joaquin rivers were significantly more abundant at depth during the day relative to night, but the results are difficult to interpret without accompanying hydrodynamic information. The mechanisms responsible for variability in migration behaviors remains unclear as are the potential benefits gained by maintaining position in the LSZ. Bennett et al. (2002), Kimmerer (2002), Kimmerer et al. (2002), Bennett (2005).

Short List of Key Papers on X2 and the Low Salinity Zone since 1995

1995

1. Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel JR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine applications. Ecological Applications 5(1): 272-289.

2001

2. Schoellhamer, DH. 2001. Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay. Coastal and Estuarine Fine Sediment Processes. Elsevier, Amsterdam, The Netherlands.

2002

3: Kimmerer WJ, Bennett, WA, Burau JR. 2002. Persistence of tidally-oriented vertical migration by zooplankton in a temperate estuary. Estuaries 25: 359-371.

4: Bennett WA, Kimmerer WJ, Burau JR. 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. Limnology and Oceanography 47: 1496-1507.

5: Monismith SG, Kimmerer WJ, Burau JR, Stacey MT. 2002. Structure and flow-induced variability of the subtidal salinity field in northern San Francisco Bay. Journal of Physical Oceanography 32: 3003-3019.

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

2004

7: Ruhl CA, Schoellhamer DH. 2004. Spatial and temporal variability of suspended-sediment concentrations in a shallow estuarine environment. San Francisco Estuary and Watershed Science 2(2): 1.

2005

8: Kimmerer WJ. (2005. Long-term changes in apparent uptake of silica in the San Francisco estuary. Limnology and Oceanography 50: 793-798.

9: Bennett WA. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3(2): 1.

2006

10: Hobbs JA, Bennett WA, Burton JE. 2006. Assessing nursery habitat quality for native smelts (*Osmeridae*) in the low-salinity zone of the San Francisco Estuary. Journal of Fish Biology 69: 907-922.

11: Kimmerer WJ. 2006. Response of anchovies dampens effects of the invasive bivalve Corbula amurensis on the San Francisco Estuary foodweb. Marine Ecology Progress Series 324: 207-218.

2007

12: Dugdale RC, Wilkerson FP, Hogue VE, Marchi A. 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.

13: Feyrer F, Nobriga ML, Sommer TR. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences 64(4): 723-734.

2008

14: Nobriga M, Sommer T, Feyrer F, Fleming K. 2008. Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*. San Francisco Estuary and Watershed Science 6(1): 1.

15: Jassby AD. 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): 2.

2009

16: Kimmerer WJ, Gross ES, MacWilliams ML. 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.

17: Enright C, Culberson SD. 2009. Salinity trends, variability, and control in the northern reach of the San Francisco Estuary. San Francisco Estuary and Watershed Science, 7(2): 3.

2010

18: Mac Nally R, Thomson JR, Kimmerer WJ, Feyrer F, Newman KB, Sih A, Bennett WA, Brown L, Fleishman E, Culberson SD, Castillo G. 2010. An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling. Ecological Applications 20(5): 1417-1430.

19: Thomson JR, Kimmerer WJ, Brown LR, Newman KB, Mac Nally R, Bennett WA, Feyrer F, Fleishman E. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications 20(5): 1431-1448.

2011

20: Feyrer F, Newman K, Nobriga M, Sommer T. 2011. Modeling the effects of future outflow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34: 120-128.

21: York J, Costas B, McManus G. 2010. Microzooplankton grazing in green water—results from two contrasting estuaries. Estuaries and Coasts 34: 373-385.

22: Winder M, Jassby AD. 2011. Shifts in zooplankton community structure: implications for food web processes in the upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

23: 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: 885-899

Summaries

1: Isohaline position as a habitat indicator for estuarine populations
Author(s): A. D. Jassby, W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski
Year: 1995
Journal: Ecological Applications
Volume: 5
Number: 1
Pages: 272-289
URL: http://sfbay.wr.usgs.gov/publications/pdf/jassby_1995_isohaline.pdf
Relevance to X2 and LSZ: This paper reports the scientific basis of using X2 (the 2% bottom salinity position) as a habitat indicator to regulate freshwater flow to the Bay Delta Estuary. Participants in EPA's initial estuarine habitat workshop recommended that standards for protecting aquatic life should be based at least in part on the estuary's physical response to fluctuations in freshwater input, i.e., on some "habitat indicator" (sensu Messer 1990, who defines habitat indicator as a "physical attribute measured to characterize conditions necessary to support an organism, population, or community in the absence of pollutants"). The salinity field was of particular interest, and X2 was found to be particularly valuable because by knowing X2 only, one can recreate the entire mean salt field in the Estuary. Additional advantages include that it can be measured with greater accuracy and precision then net freshwater inflow into the estuary. At the same time, statistical analyses demonstrate an unambiguous relationship of X2 with net Delta outflow. The recommendation for X2 as a habitat indicator are based on statistical relationships with year-to-year variability in multiple estuarine resources, including phytoplankton, mollusks, and fish. In the case of fish, clear and pervasive relationships are demonstrated with bottom-foraging fish (starry flounder) and both survival (striped bass) and abundance (longfin smelt and striped bass) of fish that feed in the water column. There is also a clear and pervasive relationship between X2 and phytoplankton-derived particulate organic carbon (POC). The response of the mollusk community is more distinctive. The mollusk abundance index, expressed as the total mollusk density in Grizzly Bay, showed a clear minimum at intermediate values of X2.

2: Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay
Author(s): D. H. Schoellhamer
Year: 2001
Book: Coastal and Estuarine Fine Sediment Processes
Editor(s): W. H. McAnally and A. J. Mehta
Publisher: Elsevier, Amsterdam, Netherlands
Pages: 373-385
URL: http://sfbay.wr.usgs.gov/sediment/elsevierPDF.html
Relevance to X2 and LSZ: The purpose of this paper is to describe how salinity, bottom topography, and tides influence the locations of the estuarine turbidity maximum (ETM), or suspended sediment concentration (SSC) maxima, in northern San Francisco Bay. ETMs form when salinity is present but they are not associated with a singular salinity. In San Francisco Bay, there is a larger salinity range for ETM location than is observed in other estuaries. The processes that account for a salinity-dependent ETM include gravitational circulation, salinity stratification, and bed storage. The longitudinal salinity gradient, not salinity, creates gravitational circulation and ETMs. All these processes occur in northern San Francisco Bay and are modified by bottom topography and tides. Bottom topography enhances salinity

stratification, gravitational circulation, and ETM formation seaward of sills. Salinity stratification in Carquinez Strait, which is seaward of a sill, is greatest during neap tides, which are the only times when tidally averaged SSC in Carquinez Strait was less than that observed landward at Mallard Island. Maximum bottom SSC measured by USGS water quality cruises was located in Carquinez Strait 67 percent of the time, and tidally averaged SSC was greater in Carquinez Strait and the Reserve Fleet Channel, which are both seaward of sills, compared with more landward sites.

3: Persistence of tidally oriented vertical migration by zooplankton in a temperate estuary
Author(s): W. J. Kimmerer, W. A. Bennett, and J. R. Burau
Year: 2002
Journal: Estuaries
Volume: 25
Number: 3
Pages: 359-371
URL: http://www.springerlink.com/content/g55tp2lx7x3r5v66/fulltext.pdf
Relevance to X2 and LSZ: Results from this study show differences among years and variability among taxa in the tidal movements of zooplankton species in the LSZ. The authors demonstrate extensive evidence showing some degree of persistence of various behaviors but were unable to determine how these translate to position maintenance. Based on the presented results, the variable bathymetry in the northern Estuary may play a key role in position maintenance. The migratory behavior of copepods was not consistent and also not responsive to changes in freshwater flow, salinity, or stratification. By contrast, mysids and amphipods responded to freshwater flow regimes. The results for copepods suggest rigid behavior regardless of changing environmental variables, whereas mysids and amphipods altered their behavior depending on local conditions related to freshwater flow. The zooplankton species differed in salinity range. The authors also observed a landward shift of the center of abundance of the copepod *Eurytemora affinis*, which appears to have coincided with the spread of the introduced clam *Potamocorbula amurensis*. They also determined that, since 1988, chlorophyll concentration has been lower in the LSZ compared to the freshwater Delta. During 1988-1998, chlorophyll was generally about 3-fold to 10-fold lower than previously for salinity values between 0.5 and 20 psu, and a consistent and occasionally steep spatial gradient was observed with higher chlorophyll at salinity values below 1 psu.

4: Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone
Author(s): W. A. Bennett, W. J. Kimmerer, and J. R. Burau
Year: 2002
Journal: Limnology and Oceanography
Volume: 47
Number: 5
Pages: 1496-1507
URL: http://www.aslo.org/lo/toc/vol_47/issue_5/1496.html
Relevance to X2 and LSZ: This paper examines the degree of flexibility in retention strategies of young fishes in the LSZ during years of highly variable river flow. Young fishes migrated vertically and maintained position in the LSZ, switching between two strategies depending on freshwater flow and longitudinal position of the LSZ. Abundances of four fish species (delta smelt, longfin smelt, striped bass, yellowfin goby) and estimated volume of detrital material were highest at the lower end of the range of salinity sampled in the LSZ. These results support previous observations (see, for example Moyle et al. 1992) showing that an assemblage of

young fishes occupies the turbid landward margin of the LSZ. In 1994, striped bass, longfin smelt, and yellowfin goby migrated tidally, occurring near the surface on flood tides and near the bottom on ebb tides. During 1995, this behavior persisted for striped bass and yellowfin goby, even though landward residual currents were present under high river-flow conditions. In contrast, during moderate freshwater flow conditions when the LSZ was positioned in the morphologically complex central Suisun Bay, fishes exhibited reverse diel migrations at the north channel sites such that they were more abundant at the surface by day and at depth by night. The authors suggest that vertical migrations may enhance feeding success, because zooplankton prey similarly migrated in the LSZ.

5: Structure and flow-Induced variability of the subtidal salinity field in northern San Francisco Bay
Author(s): S. G. Monismith, W. J. Kimmerer, J. R. Burau, and M. T. Stacey
Year: 2002
Journal: Journal of Physical Oceanography
Volume: 32
Pages: 3003-3019
URL: http://www-ce.stanford.edu/faculty/monismith/MonismithEtAl2002JPO.pdf
Relevance to X2 and LSZ: This paper provides new insights into the salinity distribution (geographically and over time) of the estuary as it relates to X2. It discusses the structure of the salinity field in northern San Francisco Bay and how it is affected by freshwater flow. Analysis of covariability of Q and X showed a characteristic timescale of adjustment of the salinity field of approximately 2 weeks in response to flow. X2 was found to be proportional to riverflow to the 1/7 power. Thus, the (geographical) length of salinity intrusion into the northern estuary turns out to be relatively insensitive to river flow. The authors argue that the relatively weak dependence of salinity intrusion on flow is owed to dynamic tidal variations, which modulate stratification in the northern estuary. Regardless, they find that X2 can be used as an unambiguous flow-dependent length (as in "distance") scale for salinity intrusion, based on the relationship of $X2 \sim Q^{1/7}$. A key finding from the analysis is a self-similar distribution (whole curve has similar shape as it parts) of depth-averaged salinity in the estuary that is proportional to 1/X2, with a salinity gradient in the center 70% of the region between the Golden Gate and X2. For improving vertically resolved models of salinity intrusion (circulation models), accurately modeling the effects of stratification may be key.

6: Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages?
Author(s): W. J. Kimmerer
Year: 2002
Journal: Marine Ecology Progress Series
Volume: 243
Pages: 39-55
URL: http://www.waterrights.ca.gov/baydelta/docs/exhibits/DOI-EXH-33I.pdf
Relevance to X2 and LSZ: Kimmerer posits that variations in the abundance or survival of fish in the northern estuary may occur through attributes of physical habitat that vary with flow. Based on reexamining responses of estuarine species to flow and changes in the foodweb (caused by the invasion of *Potamocorbula amurensis*), he concludes variation with freshwater flow of abundance or survival of organisms in higher trophic levels apparently did not occur through upward trophic transfer. All but 3 of the examined species had median salinity between 0.5 and 6, i.e. their distributions overlapped substantially with the LSZ, but large parts of their populations are outside of the LSZ. Fish (with the exception of delta smelt) and shrimp responded positively to flow, whereas chl a (i.e., phytoplankton) and several species of

zooplankton had either weak responses to flow or responses that changed after the arrival of *P. amurensis* in 1987. Following the spread of *P. amurensis,* there is a marked decreasing trend in organic matter production and plankton abundance with time, but fish and shrimp did not appear to respond to this change.

7: Spatial and temporal variability of suspended sediment concentrations in a shallow estuarine environment
Author(s): C. A. Ruhl and D. H. Schoellhamer
Year: 2004
Journal: San Francisco Estuary and Watershed Science
Volume: 2
Number: 2
Pages: Article 1
URL: http://escholarship.org/uc/item/1g1756dw#page-1
Relevance to X2 and LSZ: Sediment transport shallow water differs from that in deeper channels because of greater wind wave resuspension, closer proximity to the shore and tributaries, and greater relative benthic filtering. The U.S. Geological Survey measured suspended-sediment concentrations at five locations in Honker Bay, a shallow subembayment of San Francisco Bay, and the adjacent channel to investigate the spatial and temporal differences between deep and shallow estuarine environments. During the first freshwater pulse of the wet season, the channel tended to transport suspended sediments through the system, whereas the shallow area acted as off-channel storage where deposition would likely occur. Following the freshwater pulse, suspended-sediment concentrations were greater in Honker Bay than in the adjacent deep channel, due to the larger supply of erodible sediment on the bed. However, the tidal variability of suspended-sediment concentrations in both Honker Bay and in the adjacent channel was greater after the freshwater pulse than before. During wind events, suspended-sediment concentrations in the channel were not affected; however, wind played a crucial role in the resuspension of sediments in the shallows.

8: Long-term changes in apparent uptake of silica in the San Francisco Estuary
Author(s): W. J. Kimmerer
Year: 2005
Journal: Limnology and Oceanography
Volume: 50
Number: 3
Pages: 793-798
URL: http://www.aslo.org/lo/toc/vol_50/issue_3/0793.html
Relevance to X2 and LSZ: Kimmerer used silica distributions in the northern estuary to infer the apparent uptake of silica and diatom production. Primary production estimated from dissolved silica uptake was similar to production estimated from light and chlorophyll. Production based on dissolved silica (Si_d) averaged 1% and 17% of values prior to the introduction of *P. amurensis*. The Si uptake rates are calculated with a steady-state flux model based on measured salinity gradients and calculated hydraulic residence times. Mixing curves validate the Si-salinity relationship over a range of flow conditions but indicate a slightly negative trend in flow, particularly in June, reflecting the declining hydrograph in the transition from the spring high-flow period to the dry season. However, there is no evidence for an influence of either freshwater flow or temperature, and therefore climate change, on the long-term trend in diatom production.

9: Critical assessment of the delta smelt population in the San Francisco Estuary, California
Author(s): W. A. Bennett

Year: 2005
Journal: San Francisco Estuary and Watershed Science
Volume: 3
Number: 2
Pages: Article 1
URL: http://escholarship.org/uc/item/0725n5vk
Relevance to X2 and LSZ: Delta smelt was formally abundant in the low-salinity and freshwater habitats of the northeastern San Francisco Estuary but is now listed as threatened under the Federal and California State Endangered Species Acts. A key area of controversy centers on impacts to delta smelt associated with exporting large volumes of freshwater from the estuary to supply California's significant agricultural and urban water demands. Uncertainties about the impacts of water export operations on the delta smelt population range from limited knowledge of the numbers of larvae lost in exported water, and impacts of predators near the facilities, to the conditions promoting significant entrainment events at all life stages. Use of a population model suggests that water export operations can impact the abundance of post-larval (about 20 mm fork length) delta smelt, but these effects may not reflect on adult abundance due to other processes, such as impacts of toxic chemicals or changes to the estuarine foodweb by exotic species. Limited work to date has not shown a significant impact of toxic chemicals on delta smelt, however, the author sees a real threat considering the rapidly evolving development and use of new pesticides. Impacts due to exotic species are likely, but there are large uncertainties, in part due to the complexity of interference with delta smelt recruitment. In comparison with other fish, delta smelt has a tiny geographic range being confined to a thin margin of low salinity habitat in the estuary. It is a small and primarily annual species but with low fecundity and a protracted spawning season: key traits that are typically associated with a perennial life history strategy. Delta smelt also do not appear to compensate for their limited reproductive capacity by having precocious offspring; their larvae are pelagic. Overall, the population persists by maximizing growth, survival, and reproductive success on an annual basis despite an array of limiting factors that can occur at specific times and locations. However, population viability analysis using delta smelt abundance estimates for the entire data record (1982–2003) suggest a high probability that the population would decline post 2004.

10: Assessing nursery habitat quality for native smelts (*Osmeridae*) in the low-salinity zone of the San Francisco Estuary
Author(s): J. A. Hobbs, W. A. Bennett, and J. E. Burton
Year: 2006
Journal: Journal of Fish Biology
Volume: 609
Pages: 907-922
URL: ftp://ftp.water.ca.gov/DES/BDCP/Hobbs%20Bennet%20et_al%202006.pdf
Relevance to X2 and LSZ: Delta smelt in the north channel of Suisun Bay exhibited higher densities, larger sizes, increased somatic condition, and greater feeding success, compared to the south channel. Longfin smelt exhibited similar densities, size distributions, and feeding success between both channels, but generally showed poorer somatic condition for the south channel, potentially due to energetic costs associated with documented vertical migration behavior. Overall, the physical conditions of the north channel provided superior habitat for both species, while the south channel afforded only marginal habitat for longfin smelt and very poor habitat for delta smelt. Therefore, the north channel of Suisun Bay acts as critical nursery habitat by providing better feeding and growing conditions.

11: Response of anchovies dampens effects of the invasive bivalve *Corbula amurensis* on the San Francisco Estuary foodweb

Author(s): W. J. Kimmerer
Year: 2006
Journal: Marine Ecology Progress Series
Volume: 324
Pages: 207-218
URL: http://www.int-res.com/articles/meps2006/324/m324p207.pdf
Relevance to X2 and LSZ: When *C. amurensis* invaded the San Francisco Estuary, the distribution of northern anchovy *Engraulis mordax* shifted toward higher salinity, reducing summer abundance by 94% in the low-salinity region of the estuary. The shift in spatial distribution appears to have been a direct behavioral response to reduced food. Bioenergetic calculations showed reduced consumption of zooplankton by all planktivores, including mysids, after *C. amurensis* became abundant, and the anchovy left the low-salinity region of the estuary. This reduced consumption appears to have mitigated effects of the loss of phytoplankton productivity due to increased grazing by the invader, making a greater proportion of the zooplankton productivity available to other fish species.

12: The role of ammonium and nitrate in spring bloom development in San Francisco Bay
Author(s): R. C. Dugdale, F. P. Wilkerson, V. E. Hogue, and A. Marchi
Year: 2007
Journal: Estuarine, Coastal, and Shelf Science
Volume: 73
Pages: 17-29
URL: http://www.usc.edu/org/seagrant/Publications/PDFs/Dugdale_etal2_007.pdf
Relevance to X2 and LSZ: The authors suggest that San Francisco Bay's substantial inventory of nitrate (NO_3) is unavailable to the resident phytoplankton most of the year due to the presence of ammonium (NH_4) at inhibitory concentrations that prevent NO_3 uptake. Detailed analysis of spring blooms in three embayments over 3 years shows a consistent sequence of events that starts with improved irradiance conditions through stabilization of the water column by stratification or reduced tidal activity. Second, NH_4 concentrations are reduced to a critical range, 1 to 4 μmol per liter, through dilution by precipitation and by phytoplankton uptake. Third, the drawdown of NH_4 enables rapid uptake of NO_3 and subsequent increase in chlorophyll.

13: Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA
Author(s): F. Feyrer, M. L. Nobriga, and T. R. Sommer
Year: 2007
Journal: Canadian Journal of Fisheries and Aquatic Sciences
Volume: 64
Pages: 723-734
URL: http://www.water.ca.gov/aes/docs/FeyrerNobrigaSommer2007.pdf
Relevance to X2 and LSZ: General additive model (GAM) predictions for delta smelt, striped bass, and threadfin shad, exhibited significant long-term declines in habitat suitability in the estuary, especially in San Pablo Bay and the South Delta. Simple regression models suggest that water quality may be an important factor in the decline of delta smelt, at least during the past two decades, when food availability was severely reduced by the invasion of *C. amurensis*. The findings corroborate previous hypotheses that the area of suitable physical and chemical habitat has played a role in the decline in fish abundance.

14: Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*
Author(s): M. Nobriga, T. Sommer, F. Feyrer, and K. Fleming

Year: 2008
Journal: San Francisco Estuary and Watershed Science
Volume: 6
Number: 1
Pages: Article 1
URL: http://www.water.ca.gov/aes/docs/NobrigaSummerHabitat.pdf
Relevance to X2 and LSZ: The findings from this study support the hypothesis that basic water quality parameters are predictors of delta smelt relative abundance, but only at regional spatial scales. The authors identified three distinct geographic regions that had similar long-term trends in delta smelt capture probabilities: a primary habitat region centered on the confluence of the Sacramento and San Joaquin rivers and two marginal habitat regions, one centered on Suisun Bay and the other on the San Joaquin River and southern Sacramento-San Joaquin Delta. Three water quality variables— specific conductance (salinity), Secchi depth (clarity), and temperature—measured concurrently with fish catches all interact to influence delta smelt occurrence (distribution) in the upper San Francisco estuary and are thus indicators of abiotic habitat suitability. Long-term associations of water quality variation and relative abundance were most notable on the perimeter of the species' distribution outside of the Confluence region. Delta smelt relative abundance in the Suisun region varied in association with specific conductance, which is a function of river inflow variation. The San Joaquin region had the warmest water temperatures and the highest water clarity, which increased strongly in this region during 1970–2004. Increasing water clarity, as the authors suggest, is a long-term habitat constriction for delta smelt and a major reason for its absence in the San Joaquin region during summer.

15: Phytoplankton in the upper San Francisco Estuary: recent biomass trends, their causes and their trophic significance
Author(s): A. D. Jassby
Year: 2008
Journal: San Francisco Estuary and Watershed Science
Volume: 6
Number: 1
Pages: Article 2
URL: http://escholarship.org/uc/item/71h077r1
Relevance to X2 and LSZ: The paper examines the effect of flow on phytoplankton biomass in the context of an empirical model that attempts to separate contemporaneous flow conditions from other, perhaps unidentified, forces behind the long-term trend. Regional phytoplankton biomass trends during 1996–2005 are positive in the Delta and neutral in Suisun Bay. The trend in Delta primary productivity is also positive. Changes in phytoplankton biomass and production during the last decade are therefore unlikely to be the cause of more recent metazoan declines. Freshwater flow variability and its effect on particle residence time are the main source of interannual phytoplankton variability in the Delta, including the upward trend. This conclusion is supported by trend analyses; the concurrence of these time trends at widely-separated stations; empirical models at the annual and monthly time scales; particle residence time estimates; and experience from other estuaries. The reason behind Suisun Bay phytoplankton's low responsiveness to flow variability appears to be *C. amurensis*, which has maintained the phytoplankton community mostly at low levels by vigorous filter-feeding. In the past, flows into Suisun Bay generally diluted the higher phytoplankton concentrations within the bay; now they bring in higher phytoplankton concentrations from upstream. Accordingly, Jassby suggests loading of phytoplankton and phytoplankton-derived detritus accounts for much of the phytoplankton carbon supply to Suisun Bay. In the Delta, *Corbicula fluminea* may be conceivably responsible for a significant part of the observed interannual variability in

phytoplankton biomass. Macronutrient supply, on the basis of dissolved nutrient levels, does not seem to be important as a determinant of phytoplankton variability. Water temperature increased significantly during 1996–2005. The temperature increase is significant and, at least partially independent of flow changes, but its net effect on the phytoplankton community is unknown because of differential effects on growth and loss processes.

16: Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume?
Author(s): W. J. Kimmerer, E. S. Gross, and M. L. MacWilliams
Year: 2009
Journal: Estuaries and Coasts
Volume: 32
Pages: 375-389
URL: http://www.springerlink.com/content/26pr3h5574605083/fulltext.pdf
Relevance to X2 and LSZ: The key finding in this study is that of eight species, only two (American shad and striped bass) had habitat relationships to X2 that appeared consistent with their relationships of abundance (or survival) to X2. The authors conclude that mechanisms other than variation in physical habitat must underlie responses of abundance to flow for most species. The authors calculated an index of total habitat for each species by combining resource selection functions for salinity and depth with estimates of habitat volume at five different flows using the TRIM3D hydrodynamic model. The resource selection functions for the examined species were consistent for data from different sampling programs with the exception of longfin smelt, which had a peak resource value at salinity near 20 in the Bay Study otter trawl (sampling in deeper water, more seaward) but near 10 or less in the other samples (sampling in shallower water, more landward).

17: Salinity trends, variability, and control in the northern reach of the San Francisco Estuary
Author(s): C. Enright and S. D. Culberson
Year: 2009
Journal: San Francisco Estuary and Watershed Science
Volume: 7
Number: 2
Pages: Article 3
URL: http://escholarship.org/uc/search?entity=jmie_sfews;volume=7;issue=2
Relevance to X2 and LSZ: The key conclusion here is that climate is the primary long-term salinity *variability* driver at the seasonal and annual scale. The water projects influence the trend of the annual and some monthly means in outflow and salinity, but exert far less influence on variability. Notably, both outflow and salinity are generally more variable in the water project era concordant with watershed precipitation. However, the water projects have decoupled long-term trends in annual mean outflow and salinity from long-term trends in climate forcing. Outflow trends downward in opposition to the precipitation trend in the post-project period. The authors also note an apparent reduction in fall outflow from the Delta and salinity variability in the northern reach in the last decade as the water projects have operated more closely to maximum export-inflow ratios.

18: An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR)
Author(s): R. Mac Nally, J. R. Thomson, W. J. Kimmerer, F. Feyrer, K. B. Newman, A. Sih, W. A. Bennett, L. Brown, E. Fleishman, S. D. Culberson, and G. Castillo
Year: 2010
Journal: Ecological Applications

Volume: 20
Number: 5
Pages: 1417-1430
URL: http://online.sfsu.edu/~modelds/Files/References/MacNallyetal2010EcoApps.pdf
Relevance to X2 and LSZ: The authors applied a Bayesian (probabilistic) analysis framework to validate fifty-four relationships representing the state of knowledge of how abiotic habitat factors directly relate to declining fish abundance in the upper San Francisco Estuary and indirectly to these fish populations through the food web. An underlying expert model specified whether particular trophic or covariate effects might be influential. X2 and increased water clarity over the period of analyses were two factors affecting multiple declining taxa (including fishes and their main zooplankton prey). There was a pervasive relationship of spring X2 with abundances of longfin smelt. There is evidence of potential effects of water exports on delta smelt and threadfin shad. Increases in water exports in both winter and spring were negatively associated with abundance of delta smelt and increases in spring exports with abundance of threadfin shad. The results for delta smelt were consistent with multiple effects of temperature, feeding, exports, and introduced species. The results for striped bass are consistent with effects of feeding and water clarity. Covariates (factors thought to be important for one or more of the response variable) explained 51% variation, suggesting that some aspects of the environment that can be managed are associated with the declining fish species (e.g., X2 and exports). Other potential remedial actions would be difficult or impossible to enact (e.g., total removal of *C. amurensis*).

19: Bayesian change-point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary
Author(s): J. R. Thomson, W. J. Kimmerer, L. R. Brown, K. B. Newman, R. Mac Nally, W. A. Bennett, F. Feyrer, and E. Fleishman
Year: 2010
Journal: Ecological Applications
Volume: 20
Number: 5
Pages: 1431-1448
Relevance to X2 and LSZ: By using multispecies change point models, the authors find strong evidence for a common change point for all POD species in 2002. Abiotic variables, including water clarity, position of X2, and the volume of freshwater exported from the estuary, explained some variation in species' abundances over the time series, but no selected covariates could explain statistically the post-2000 change points for any species. Species-specific, covariate-conditioned change point models indicated step declines in abundances (i.e., abrupt declines that could not be modeled by the included covariates) of delta smelt and longfin smelt in 2004 and of striped bass and threadfin shad in 2002. In a variable-selection model for delta smelt, water clarity and winter exports both had high probability of inclusion and a negative effect. In the variable-selection model for longfin smelt, water clarity and spring X2 had high probability of inclusion. In the variable-selection model for striped bass, water clarity and the autocorrelation term had high probability of inclusion. No variables had high probability of inclusion in the threadfin shad variable selection model. The authors used a hierarchical Bayesian modeling framework, which allows sampling or measurement error to be separated from actual variation in underlying abundances, while fitting a wide variety of process models.

20: Modeling the effects of future outflow on the abiotic habitat of an imperiled estuarine fish
Author(s): F. Feyrer, K. Newman, M. Nobriga, and T. Sommer
Year: 2011
Journal: Estuaries and Coasts

Volume: 34
Pages: 120-128
Relevance to X2 and LSZ: The authors report a 78% decrease in an annual abiotic habitat index for delta smelt over the study period (1967 – 2004). Using the General Additive Model developed by Feyrer et al. (2007), only specific conductance and Secchi depth accounted for a meaningful reduction of null deviance (i.e., unexplained variability). The final model with specific conductance and Secchi depth accounted for 26% of the deviance. The CALSIM II model was used to simulate future X2 scenarios under seven different development (each assuming a constant level of development) and climate change scenarios, representing a range of drier and wetter possibilities. Modeled future conditions produced smaller values of the delta smelt habitat index relative to the modeled present day condition, the only exception being in critical years when all values were similar and low. These modeling results suggest further declines in habitat across all water year types. The authors conclude that recovery targets for delta smelt will be difficult to attain if the modeled habitat conditions are realized. A key part of the concern for delta smelt is that the lowest levels of suitable habitat coincide with the habitat being located further upstream in closer proximity to anthropogenic sources of mortality such as water diversions and certain contaminant sources. Locations of X2 downstream of the confluence of the Sacramento and San Joaquin rivers results in a dramatic increase in the habitat index, when the LSZ encompasses the expansive Suisun and Grizzly Bays, a larger area of suitable habitat.

21: Microzooplankton grazing in green water—results from two contrasting estuaries
Author(s): J. York, B. Costas, and G. McManus
Year: 2011
Journal: Estuaries and Coasts
Volume: 34
Pages: 373-385
URL: http://online.sfsu.edu/~modelds/Files/References/YorkEtAl2010EstuariesCoasts.pdf
Relevance to X2 and LSZ: Using the dilution method to measure seasonal variations in microzooplankton grazing on phytoplankton, the authors found many instances of saturated as well as insignificant grazing in San Francisco Bay. They suggest that saturation in some cases may result from high particle loads and that insignificant grazing may result from extreme saturation of the grazing response due to the need to process non-food particles. There was no evidence of nutrient limitation for phytoplankton growth. In a series of two-point dilutions run in spring and summer 2007, the authors found increasing phytoplankton growth rates and microzooplankton grazing rates with increasing salinity. Grazing rates in San Francisco Bay and Long Island Sound were similar to those found in other estuaries.

22: Shifts in zooplankton community structure: implications for food web processes in the upper San Francisco Estuary
Author(s): M. Winder and A. D. Jassby
Year: 2011
Journal: Estuaries and Coasts
Volume: 34
Pages: 675-690
URL: http://www.springerlink.com/content/b30544u2xx0l235u/fulltext.pdf
Relevance to X2 and LSZ: This paper documents major changes in the zooplankton species composition in Suisun Bay and the Delta between 1972 and 2008, largely associated with direct and indirect effects of introductions of non-native bivalve and zooplankton species. Previously dominant copepod species were essentially replaced by newly introduced species over the 37-year study period. Major changes occurred also within the mysid community, with a strong decline in biomass by the end of the 1980s and species composition changes in the early

1990s. In Suisun Bay, the historically abundant calanoid copepods and rotifers have declined significantly, but their biomass has been compensated to some extent by the introduced cyclopoid *Limnoithona tetraspina*. The increasing dominance of *L. tetraspina* in the early 1990s in Suisun Bay coincided with declining trends in the average micro- and mesozooplankton size in this region. The Delta has also experienced long-term declining biomass trends, particularly of cladocerans and rotifers, although calanoid copepods have increased since the early 1990s due to the introduced *Pseudodiaptomus spp*. However, zooplankton biomass in the Delta has remained at a low level since the mid-1980s. Changes in the biomass, size, and possibly chemical composition of the zooplankton community imply major alterations in pelagic food web processes, including a drop in prey quantity and quality for foraging fish and an increase in the importance of the microbial food web for higher trophic levels.

23: 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
Author(s): D. H. Schoellhamer
Year: 2011
Journal: Estuaries and Coasts
Volume: 34
Pages: 885-899
URL: http://bayplanningcoalition.org/wp-content/uploads/Schoellhamer-2001-sudden-clearing.pdf
Relevance to X2 and LSZ:

The paper presents a quantitative conceptual model of an estuary with an erodible sediment pool and transport or supply regulation of sediment transport. The author offers a hypothesis that the Bay contained an erodible pool of sediment that was depleted in the late 1990s. The hypothesis is supported by an analysis of historical changes in bed sediment volume. The study was motivated by a statistically significant 36% step decrease in SSC in San Francisco Bay from water years 1991–1998 to 1999–2007. This step change in the water year mean SSCs from WY 1998 to 1999 was significant (one-sided rank-sum test $p<0.01$) at all sites except San Mateo Bridge. At the interannual time scale of this study, an erodible sediment pool is the difference between the existing sediment mass and the sediment mass of the estuary at equilibrium (no net deposition or erosion). An erodible sediment pool is depleted when transport-regulated suspension becomes supply-regulated. When regulation of suspended sediment crosses the threshold from transport regulation to supply regulation, suspended mass can rapidly decrease. At the interannual time scale, the erodible sediment pool is larger than at the tidal time scale. Changes in the erodible sediment pool caused by changes in hydrodynamic forcing, specifically decreased tidal prism due to construction fill and levees, are assumed to be negligible. Application of the quantitative conceptual model to San Francisco Bay demonstrates that depletion of an erodible sediment pool in 1999 would cause a sudden decrease in SSC. Supply of hydraulic mining sediment increased bed sediment volume by at least 260 Mm^3 in the late 1800s, almost entirely in Suisun and San Pablo Bay. From the early to mid-1900s, there was a second pulse of sediment about 60% of the hydraulic mining sediment pulse and conceivably caused by urbanization or increased agricultural land use. Without an erodible sediment pool, annual suspended mass would be dependent on river supply and would not suddenly decrease, unless the river supply suddenly decreased. The river supply to San Francisco Bay varies annually and decreased 1.3%/year during the later half of the twentieth century (Hestir et al. submitted). The decreasing watershed sediment supply contributes to decreased SSC but cannot account for the step decrease in SSC. According to the author, changes in the San Francisco Bay ecosystem in the 2000s have been symptomatic of the sudden clearing.

Appendix 4: Notes on Estimating X2

Notes on estimating X2, the distance from the Golden Gate to 2 ppt Salinity (km)

These notes were prepared to accompany an excel workbook (that will be available at the workshop if not before) containing 1930-2011 DAYFLOW and X2 data for use by IEP. The last two pages of these notes contain notes about X2 and outflow values available in CDEC and the now discontinued DWR/IEP HEC-DSS database. A compilation of CDEC outflow (1994-present) and X2 (2007-present) data is available.

NOTE: THE X2 EQUATION (equation 1, below) IS 20 YEARS OLD. MUCH MORE SALINITY AND FLOW DATA ARE NOW AVAILABLE THAN WHEN THE EQUATION WAS FIRST ESTABLISHED 20 YEARS AGO. THERE ARE SIGNIFICANT DISCREPANCIES BETWEEN X2 VALUES IN DAYFLOW AND IN CDEC. PROCEDURES FOR ESTIMATING X2 SHOULD BE REEVALUATED USING ALL CURRENTLY AVAILABLE DATA AND PERHAPS NEW MODELING APPROACHES.

X2 values in DAYFLOW (http://www.water.ca.gov/dayflow/documentation/dayflowDoc.cfm#Introduction):

According to the DAYFLOW documentation, "The 1994 Bay-Delta agreement established standards for salinity in the estuary. Specifically, the standards determine the degree to which salinity is allowed to penetrate up-estuary, with salinity to be controlled through delta outflow. The basis for the standards is a series of relationships between the salinity pattern and the abundance or survival of various species of fish and invertebrates. These relationships have been expressed in terms of X2, the distance from the Golden Gate to the point where daily average salinity is 2 parts per thousand at 1 meter off the bottom (Jassby et. al. 1995)."

DAYFLOW X2 estimates are available starting on October 1, 1996. In DAYFLOW, X2 is estimated using the Autoregressive Lag Model:

1. $X2(t) = 10.16 + 0.945*X2(t-1) – 1.487\log(QOUT(t))$
   where t = current day and t-1 = previous day

Daily X2 Estimates for the 1930-2011 time series in <u>THIS WORKBOOK</u>:

As in DAYFLOW and elsewhere, equation 1 and DAYFLOW's daily "Net Delta Outflow Index" (NDOI) values are used for all daily X2 estimates from 1930-2011. In contrast to previous X2 estimations, however, the outflow value is set to a fixed outflow of 50 cfs for days with negative net Delta outflow. The only exception is June 3 –June 5, 2004, when the X2 estimates given in DAYFLOW are used. See C2, below, for more information.

Additional information for estimating X2

A. <u>Origin:</u>

The X2 equation used in DAYFLOW was first published in Appendix A of the 1993 "Schubel report" (SFEP 2003). It was developed to "fill in the gaps" in a daily X2 time series that was developed by interpolating actual salinity measurements. The equation is an autoregressive model with lag 1 and an additional variable, log outflow. It was fitted with outflow and X2 data for 1975-77 (>1000 data points). The Schubel report Appendix A was written in 1992 by Kimmerer and Monismith based on work by participants in the "Schubel workshop" and especially Alan

Jassby who wrote Appendix 2 of the Schubel report. All later equations and publications are based on this work. In Appendix A of the 1993 Schubel report, Kimmerer and Monismith also give an equation for estimating monthly X2 values:

2. X2(t) = 122.2 + 0.3278*X2(t-1) – 17.65log(QOUT(t))
   where t = current month and t-1 = previous month

B. Later X2 equations:

3. Jassby et al 1995: X2(t)= 8 + 0.945*X2(t-1) – 1.5log(QOUT(t))
4. Jassby et al 1995 cited in Monismith, Kimmerer, et al (2002): X2(t)= 10.2 + 0.945*X2(t-1) – 2.3log(QOUT(t))
5. Monismith, Kimmerer, et al (2002): X2(t)= 0.919*X2(t-1) +13.57(QOUT(t)^-0141)
6. DWR Modeling Support Branch 1994: X2(t)= 14.53 + 0.926*X2(t-1) – 2.192log(QOUT(t))

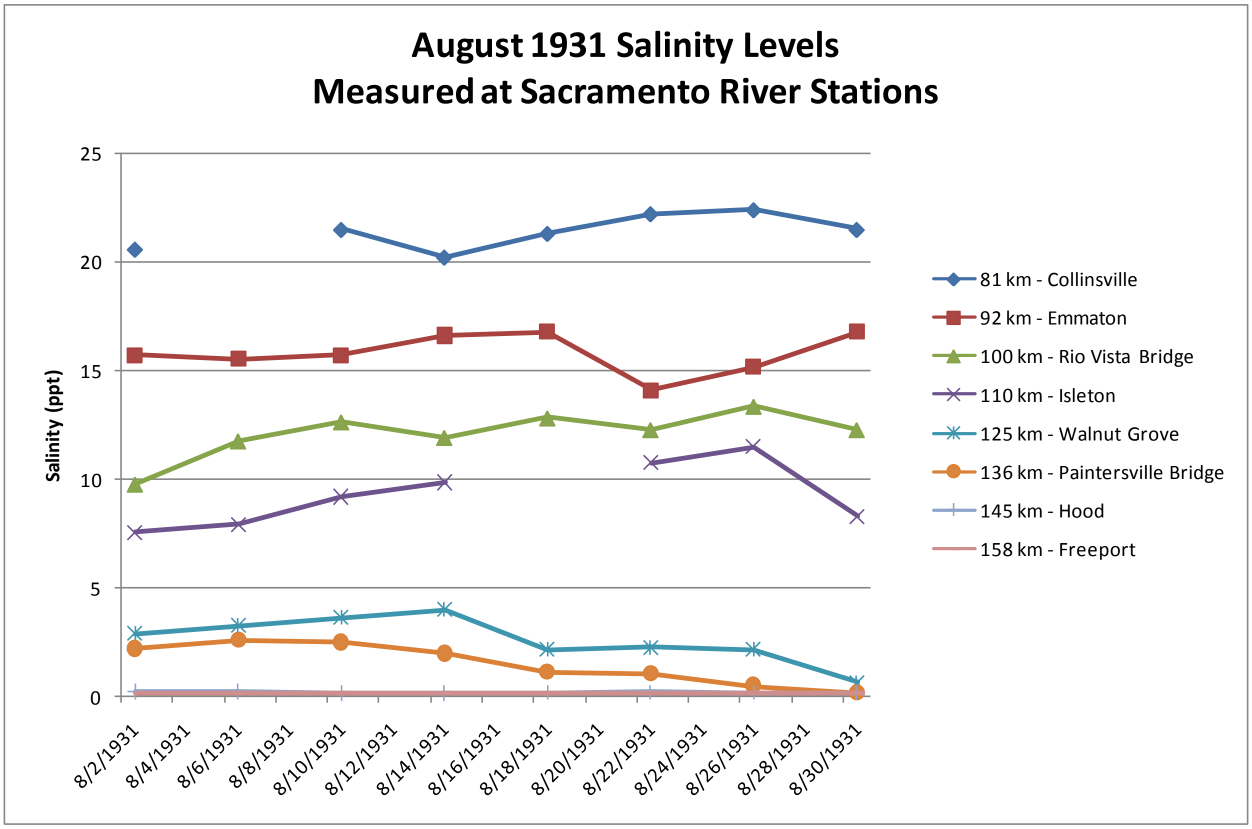
C. Problems with estimating X2 from outflow:

1. Equations 3., 4., and 5. don't give reasonable results – why? (see "X2Computation" worksheet)
2. Negative net Delta outflow: This happens fairly rarely, but it can be associated with extreme salinity intrusion during droughts. Due to spring-neap variations in flow, it is in reality perhaps also more common than the calculated Net Delta Outflow Index in DAYFLOW would suggest, see http://www.water.ca.gov/dayflow/ndoVsNdoi/ . In equation 1, X2 is estimated with log outflow. The log of a negative number does not exist. Moreover, daily X2 estimation requires an X2 value the previous day and gaps in the daily time series should thus be filled. In the Schubel report Appendix A, Kimmerer & Monismith noted that negative outflows were likely "being underestimated" in DAYFLOW (page A-6). They recommended setting "the value of log outflow for [days with negative outflow] to a minimum outflow of 316 cfs." They did not give a reason for this particular value. Following this recommendation produces what generally look like reasonable results.

   I decided, however, to use a substitution value of 50 cfs because this produces X2 estimates that correspond more closely to some observed salinity values, as follows. This should, however, be examined more carefully with additional data. Note that the choice of substitution value makes a difference only during the relatively rare negative outflow periods and a few months immediately following these periods.

   a. Net Delta outflow was negative during June 3-5, 2004, due to the Jones Tract levee break. Instead of using a substitution value, DAYFLOW used X2 values calculated from actual EC data measured at Pittsburg and Antioch, see http://www.water.ca.gov/dayflow/docs/2004comments.pdf . Estimating X2 with equation 1 with an outflow substitution value of 316 underestimated X2 during the three negative outflow days in June 2004 and for about 2 months afterward. An outflow substitution value of 50 produced much better agreement, see X2Computation worksheet.
   b. Net Delta outflow was often negative for prolonged periods in the extreme drought years of the 1930s. Salinity data for some of these years is available in a 1931 report (http://www.archive.org/details/variationcontrol27calirich) and DWR's Delta Atlas (http://baydeltaoffice.water.ca.gov/DeltaAtlas/04-WaterQuality.pdf) shows maximum

salinity intrusions for 1921-1943. For 1931, the Delta Atlas shows that "1000 parts of chloride per million parts of water" (about 1.8 ppt salinity) were measured on the Sacramento River between Courtland and Hood, i.e. at approximately 140 km from the Golden Gate. The 1931 report shows salinity of >2ppt at Paintersville Bridge (approx. 136 km from the GG) in the first half of August 1931 (see Figure below). Using a negative outflow substitution value of 316 produces an average August 1931 X2 value of 116.5 km. A substitution value of 50 produces an average August 1931 X2 value of 137 km, i.e. much better agreement with the recorded salinity values.



References:

- 1931 Salinity report, http://www.archive.org/details/variationcontrol27calirich
- SFEP 1993 with Kimmerer & Monismith Appendix A, 1992, http://www.epa.gov/region9/water/watershed/sfbay-delta/pdf/Schubel-Report.pdf
- DWR 1994, http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/wq_control_plans/1995wqcp/admin_records/part03/063.pdf

- Jassby et al 1995, http://sfbay.wr.usgs.gov/publications/pdf/jassby_1995_isohaline.pdf
- Monismith et al 2002, http://www-ce.stanford.edu/faculty/monismith/MonismithEtAl2002JPO.pdf
- DWR's Delta Atlas (http://baydeltaoffice.water.ca.gov/DeltaAtlas/04-WaterQuality.pdf

Daily X2 estimates on CDEC (pers com. Joni Hirabayashi, DWR, 9/12/2011)

In CDEC, daily X2 data starting in 2007 is available under the station name "CX2," see http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=CX2 .

On 9/16 and 9/27, 2011, CDEC posted the following description of the CX2 computation and data flags: The X2 value for station CX2 is linearly interpolated for the 2.64 uS/cm EC location among these four river mileages measuring from the SF Golden Gate Bridge: Martinez (MRZ, 56 km), Port Chicago (PCT, 64 km), Chipps Island (74 km) and Collinsville (CLL, 81 km).

"v" flag : the calculated value is less than 56.0 km or greater than 81.0 km.

On 9/12/2011, I obtained the following additional information from Joni Hirabayashi, DWR:

The X2 value for CDEC "station" CX2 (http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=CX2) is interpolated from the daily EC at the four X2 stations: Martinez (MRZ, 56 km), Port Chicago (PCT, 64 km), Mallard (MAL, 74 km) and Collinsville (CLL, 81 km). The formula was developed by engineers in DWR's O&M Operations Control Office.

CX2=(((2.64 – wEC) * (wkm – ekm))/ (wEC – eEC))+ wkm
Where:
wEC = daily EC of the westerly Station
eEC = daily EC of the easterly Station
wkm = kilometers of the westerly Station
ekm = kilometers of the easterly Station

Where EC =2.64 falls among the four stations determines which station pair is used. X2 values out of the 56 – 81 km range are not considered valid (Martinez EC < 2.64 or Collinsville EC > 2.64).

Daily Net Delta Outflow Index estimates on CDEC
Daily Delta Outflow starting in 1994 is available at http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=DTO . There is no documentation posted about how this is calculated.

On 2/14/2012, I obtained the following information from Andy Chu, DWR:
"DTO" stands for DELTA TOTAL OUTFLOW. It is a calculated value, it is not measured. This term is commonly interchanged with "NET DELTA OUTFLOW INDEX", or NDOI, as reported in DAYFLOW. However, DTO values posted on the CDEC are typically NOT cross-checked on a real-time basis. More accurate NDOI numbers that are updated every business day are available at http://www.water.ca.gov/swp/operationscontrol/deltaops.cfm , "Hydrologic Conditions Summary."

CDEC DTO is calculated as follows:

NET DELTA OUTFLOW INDEX = INFLOW INTO DELTA - NET DELTA CONSUMPTIVE USE - CVP/SWP EXPORTS - CONTRA COSTA CANAL - BARKER SLOUGH PP

Where:

INFLOW INTO DELTA = SACTO RIV FREEPORT + SACTO CO WASTE WT TRTMNT + YOLO BYPASS + EAST SIDE STREAMS + MISCELLANEOUS - FORTHCOMING + SJ RIV FLOW VERNALIS

And:
CVP/SWP EXPORTS = CLIFTON COURT INFLOW - BYRON BETHANY DELIVERIES + TRACY PP TOTAL

One final note on net Delta outflow:

As mentioned above, "outflow" in DAYFLOW and CDEC is really a calculated "Net Delta Outflow Index" (NDOI), not a measured value. This is in contrast to "Net Delta Outflow," (NDO), which according to the DAYFLOW documentation (http://www.water.ca.gov/dayflow/ndoVsNdoi/) is a more direct estimate of daily average flow based on 15 minute USGS ultrasonic velocity meter (UVM) flow data from four stations. NDO is calculated as the sum of flows from these four stations:

NDO = Rio Vista + Three Mile Slough + Jersey Point + Dutch Slough
Where:
Rio Vista = Sacramento River at Rio Vista UVM
Three Mile Slough = Three Mile Slough at San Joaquin River UVM
Jersey Point= San Joaquin River at Jersey Point UVM
Dutch Slough = Dutch Slough at Jersey Island UVM

NDO data have been available in an U.S. Army Corps of Engineers' Hydrologic Engineering Center Data Storage System (HEC-DSS) database system that was maintained by the Department of Water Resources and the IEP. This database was recently discontinued. Archived historical HEC-DSS data is available for downloading as DSS data files at http://www.water.ca.gov/iep/products/data/dssnotice.cfm .

Appendix 5: Workshop Agenda and Process

BEGINS ON NEXT PAGE

Technical Workshop on Estuarine Habitat in the Bay Delta Estuary

Managing the Low Salinity Zone to Protect Estuarine Habitat and Aquatic Life

27 March 2012
9:00 am – 4:30 pm
(please arrive by 8:30)
Cal/EPA Coastal Room, 2nd Floor
1001 "I" Street, Sacramento 95814

Purposes of the Workshop

❖ Increase our collective understanding about the attributes of estuarine habitat, and the tools we have for protecting it.

❖ Characterize the response of biological indicators and ecological processes to changing locations of the low salinity zone (LSZ).

❖ Generate scientific information that EPA and others can translate into recommendations that support the State's Comprehensive Review of the 2006 Water Quality Control Plan (WQCP) for the Bay Delta Estuary.

Workgroup Questions[1]

1. What are the key points of scientific agreement, disagreement, and uncertainty surrounding estuarine habitat and aquatic life in the Bay Delta Estuary? How can scientists and agencies "manage the uncertainty" while advancing the protection of estuarine habitat and aquatic life?

2. What is needed to update and improve the State's current approach of protecting estuarine habitat with a springtime salinity standard (FEB-JUN)? Which scientific discoveries and modeling techniques emerging since 1995 should be applied toward managing the LSZ?

3. (a) What are the drivers in the quantity of estuarine habitat during each season of the year?
(b) What are the drivers in the quality of estuarine habitat during each season of the year?
(c) What biological indicators respond to changing locations of the LSZ east of the Carquinez Strait? Please record your ideas on the attached chart of biological indicators and metrics.

4. Given the historical and present-day relationships between the LSZ and the landscape of the Bay Delta, how can models be used to forecast the response of selected biological indicators to changing precipitation patterns, rising sea levels, and restoration scenarios?

[1] Tim Vendlinski drafted these questions with excellent input and suggestions from Brock Bernstein, Erin Foresman, Robin Grossinger, Bruce Herbold, Michael MacWilliams, B.J. Miller, Stephen Monismith, and Karen Schwinn.

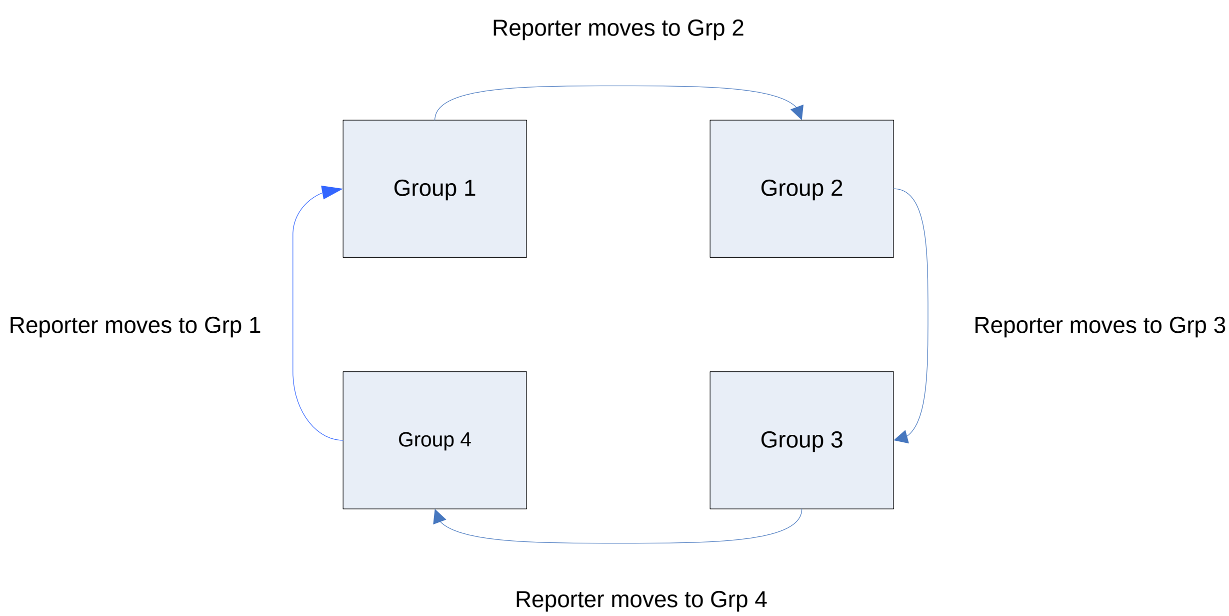
Agenda

8:30 – 9:00	Arrive; get settled; enjoy bagels, coffee, and juice	
9:00 – 9:10	Welcome and introductions	Karen Schwinn (EPA)
9:10 – 9:20	Agenda overview	Brock Bernstein
9:20 –9:45	Historical Perspectives on the Estuarine Gradient	Robin Grossinger Aquatic Science Center
9:45 –10:10	Modeling Estuarine Processes using SUNTANS	Stephen Monismith Stanford University
10:10 –10:35	Modeling Estuarine Processes using UnTRIM	Michael MacWilliams Delta Modeling Assoc.
10:35–10:40	Reflections on presentations and transition to workgroups	Brock Bernstein
10:40 – 10:50	Workgroup instructions and assignments	Brock Bernstein
10:50 – 12:15	First workgroup session – Prepare first draft of discussion summaries	
12:15 – 1:30	**Working lunch** Second workgroup session – Review and revise discussion summaries	
1:30 – 2:30	Third workgroup session – Review and revise discussion summaries	
2:30 – 2:45	**Break**	
2:45 – 4:15	Group discussion – discussion summaries	Brock Bernstein
4:15 – 4:30	Wrap up and adjourn	Brock Bernstein

Process for Technical Teams

The following workshop process is intended to increase the amount of direct interaction among participants, accelerate the refinement of ideas and products through multiple rounds of review and revision, and ensure that participants have the opportunity to address all topics.

- Break into four pre-assigned technical teams of equal size.
- Designate a team leader and reporter for each team (already done).
- Assign each team (and each reporter) one of the four workshop questions.
- The reporters are paired with the questions and will rotate among the four teams (see figure below). This builds momentum toward enriching the answer to each question, and provides continuity as each question is cycled from team to team.
- Team leaders are charged with keeping their team focused on the task at hand, bringing the best work out of each individual, synthesizing ideas to make conceptual breakthroughs, and ensuring ideas are accurately captured and conveyed to the reporter.
- **First session:** Each team responds to the assigned question.
- Reporters and questions rotate to the next team.
- **Second session:** Reporters brief their new team on the progress made by the previous team toward answering the assigned question. Each team critiques and revises the previous team's product.
- Reporters and questions rotate again.
- **Third session:** Repeat the briefing, critique, and revision of the previous group's product.
- **Group Discussion:** The workshop facilitator will reconvene all the workshop participants. Reporters and team leaders will: (i) describe how the answer(s) to each question evolved as they moved from team to team; and (ii) summarize the key points catalyzed during the collaborative process.



BIOLOGICAL INDICATOR	METRIC
FISH, SHELLFISH, AND OTHER ORGANISMS	

FOOD PRODUCTION	

PRODUCTIVITY OF THE PHOTIC ZONE	

ECOSYSTEM PROCESSES	

CONTAMINANTS	

SITE SPECIFIC STRESSORS	

SAMPLE BIOLOGICAL INDICATOR *SAMPLE* METRIC

RESPONSE OF FISH STUDIED AT "X2" WORKSHOPS	
Neomysis mercedis	Metric TBD
Crangon franciscorum	Metric TBD
Molluscs	Metric TBD
Striped bass	Metric TBD
Starry flounder	Metric TBD
Longfin smelt	Metric TBD

FOOD PRODUCTION	
Area of Low Salinity Zone	Hectares
Volume of Low Salinity Zone	Cubic Meters
Time LSZ Spends in Proximity to Productive Habitat	Minutes

PRODUCTIVITY OF THE PHOTIC ZONE	
Depth of Penetration by Sunlight through Water Surface	Centimeters
Turbidity	Nephelometric **Turbidity Unit** (NTU)

ECOSYSTEM PROCESSES	
Diversity of Aquatic Habitat at Four Cross Sections	Numerical Index TBD for Habitat Structure for Fish, e.g., # of feeding spots, # of hiding spots.
Diversity of Flow Patterns at Four Cross Sections	Metric TBD
Interfaces of Currents with Accumulations of Food	Metric TBD

CONTAMINANTS	
Ammonium	Inhibit diatoms/promote microcystis (µmol L^{-1})[2]
Selenium	Biological capture by overbite clams (µg L^{-1})[3]

SITE SPECIFIC STRESSORS	
Time LSZ Spends in Proximity to Outfalls	Minutes
Time LSZ Spends in Proximity to Pumps	Minutes
Time LSZ Spends in Proximity to *Egeria* Beds	Minutes
Time LSZ Spends in Proximity to Deep Channels	Minutes
Time LSZ Spends in Proximity to Power Plants	Minutes
Time LSZ Spends in Proximity to CVP/SWP Effects	Minutes

[2] See Dugdale's model
[3] See models by Luoma & Presser (fate of Se) and by Jan Thompson (clam abundance)

Appendix 6: Workgroup Members and Assignments

Note that reporters did not remain with their original workgroups but rotated from workgroup to workgroup with their assigned question.

Les Grober (Question 1): Group C to Group B to Group A
Jon Rosenfeld (Question 2): Group D to Group C to Group B
Ted Sommer (Question 3): Group A to Group D to Group C
Steve Culberson (Question 4): Group B to Group A to Group D

Participating scientist	**Affiliation**	**Role**
Workgroup A		
Val Connor	Water contractors	Team Leader
Jon Burau	US Geological Survey	
Mike Chotkowski	US Fish & Wildlife Service	
Robin Grossinger	San Francisco Estuary Inst.	
Ted Sommer	Dept. Water Resources	Reporter Question 3
Mark Stacy	UC Berkeley	
Workgroup B		
Larry Brown	US Geological Survey	Team Leader
Steve Culberson	US Fish & Wildlife Service	Reporter Question 4
Kathy Hieb	Dept. Fish & Game	
Stephen Monismith	Stanford Univ.	
Erwin van Nieuwenhuyse	US Bureau of Reclamation	
Matt Nobriga	US Fish & Wildlife Service	
Workgroup C		
Anke Mueller-Solger	Interagency Ecological Program & DSC	Team Leader
Bill Bennett	UC Davis	
Les Grober	State Water Resources Control Board	Reporter Question 1
Bruce Herbold	US Environmental Protection Agency	
Josh Israel	US Bureau of Reclamation	
Michael MacWilliams	Delta Modeling	
BJ Miller	Consultant	
Workgroup D		
Jan Thompson	US Geological Survey	Team Leader
Randy Baxter	Dept. Fish & Game	
Chris Enright	DSC & Dept. Water Resources	
Lenny Grimaldo	US Bureau of Reclamation	
Jon Rosenfield	TBI	Reporter Question 2
Dave Schoellhamer	US Geological Survey	