WORKING DRAFT

Role of Nutrients in Shifts in Phytoplankton Abundance and Species Composition in the Sacramento-San Joaquin Delta

Charge for the White Paper

The objectives of the white paper are to: 1) describe what is known about the importance of nutrient loads, forms, and ratios to the decrease in primary productivity and shifts in algal species composition in the Delta and Suisun Bay; 2) identify significant unresolved science questions; and 3) provide recommendations for future research and monitoring.

The primary input to the white paper will be a 2-day workshop that provides background on the Delta ecosystem and research pertinent to two hypotheses of nutrients' role in phytoplankton growth. An independent white paper author in coordination with a panel of experts will summarize results of the workshop and then use the summary, additional literature and professional expertise to create a final white paper. Ultimately, the white paper will be used to design studies and nutrient management activities in the Delta and Suisun Bay and potentially the San Francisco Bay.

Background and Project Scope

The Sacramento-San Joaquin Delta defines the freshwater portion of the San Francisco Estuary. The watershed that drains to the Estuary covers about 40% of California. Suisun Bay is the transition zone between fresh and salt water at the eastern end of San Francisco Bay. In the early 2000s, scientists' recognized a sharp decrease in populations of pelagic fish species in the Delta and Suisun Bay. Among the factors being investigated as contributing to the pelagic organism decline are a decrease in primary productivity and changes in phytoplankton community composition. The role of nutrients (e.g., forms, ratios, concentrations, and loads) in promoting changes in phytoplankton abundance and species composition is the subject of a white paper that will guide future research and monitoring.

The San Francisco Bay and Central Valley Regional Water Quality Boards which are two State agencies responsible for protecting water quality in the Estuary, are organizing the workshop and white paper in response to direction from the Delta Stewardship Council.

The mission of the Delta Stewardship Council is to implement the coequal goals adopted by the California Legislature: to provide a more reliable water supply for California and to protect, restore, and enhance the Delta ecosystem. The Council

adopted a Delta Plan in 2013 to implement these goals. The Delta Plan Chapter 6 Recommendation # 8 states, in part,

> "…the State Water Resources Control Board and the San Francisco Bay and Central Valley Regional Water Quality Control Boards should prepare and begin implementation of a study plan for the development of water quality objectives for nutrients in the Delta … The Water Boards should adopt and begin implementation of nutrient objectives, either narrative or numeric, where appropriate, in the Delta… by January 1, 2018.

Potential nutrient related problems identified in the Delta Plan for evaluation are:

1. Decreases in algal abundance and shifts in algal species composition, resulting in potential food web impacts
2. Increases in the abundance and distribution of macrophytes, including water hyacinth and Brazilian waterweed
3. Increases in the magnitude and frequency of cyanobacteria blooms

This charge is to develop a white paper that addresses the first issue, assessing whether the observed decrease in algal abundance and shift in algal species composition in the Delta and Suisun Bay are the result of long term changes in nutrient loads and whether nutrient management might remedy the food web impacts. White papers focused on the last two issues have been completed and the knowledge gap documents are almost complete.

The white papers produced under the Delta Nutrient effort will be used to draft a Nutrient Research Plan for review by the Delta Nutrient Stakeholder and Technical Advisory Group (STAG) and the State Water Resources Control Board's nutrient objectives Independent Science Review Panel. A final Nutrient Research Plan addressing all review comments will be presented to the Central Valley Regional Water Board and the Delta Stewardship Council in 2017. Results from the research conducted under the Nutrient Research Plan may be utilized by the Water Board to direct staff to develop nutrient water quality objectives (narrative and/or numeric) if warranted.

It is recognized that nutrients (e.g., forms, ratios, concentrations and loads) is only one of many drivers of phytoplankton production in the Delta and Suisun Bay, others of which include water export, contaminants, optical properties, water residence time, and food web interactions (Jassby 2008; Meyer *et al.* 2009). It is not the objective of this white paper to develop a quantitative analysis of the various drivers of phytoplankton in the Delta and Suisun Bay although a list of references that address other drivers will be

available to the white paper author and workshop panel to provide context for their focus on nutrients. This white paper will provide one additional piece toward that fuller understanding and will help us to understand when nutrient-related factors are most important and what other physical, chemical, and biological conditions must exist in order for nutrient-related factors to be critical.

As available, information on the relative importance of nutrients and other drivers will be incorporated into the Delta Nutrient Research Plan; however, it is anticipated that additional information will be needed and possibly mathematically modeled to fully understand the relative importance of nutrients and other factors in controlling phytoplankton.

Current Nutrient Hypotheses and Research Tracks Related to Decreased Algal Abundance and Species Shifts

In the Bay-Delta Estuary, and in particular Suisun Bay, there has been significant reduction of phytoplankton biomass and primary production (Alpine and Cloern 1992). A number of researchers have attributed this change to grazing by clam species which invaded San Francisco Bay and established a significant presence in 1987.

Two nutrient-focused hypotheses have recently been proposed to help explain shifts in the food web in Suisun Bay and the Delta. One hypothesis concerns the effect of elevated concentrations of ammonium on phytoplankton biomass and community composition. This hypothesis is referred to as the "ammonia paradox" (Dugdale *et al*., 2012). The hypothesis states that elevated concentrations of ammonium (NH_4) suppress nitrate (NO_3) uptake in some algal groups commonly present in the Delta. The resulting lack of access to NO_3 results in a decrease in primary production rates and, if some algal functional groups are differentially sensitive to NH_4, to shifts in community composition from more to less NH_4 sensitive algal forms.

The second hypothesis concerns the influence of nutrients on algal community composition and algal nutritional quality to herbivores and is referred to as the "Ecological Stoichiometry" hypothesis (Glibert 2010). The hypothesis states that changes in the forms and ratios of nutrients (NH_4:NO_3, N:P) cause "shifts" in algal community composition, and that these effects occur even when nutrient concentrations are in surplus and not limiting algal growth rates. Increasing N:P and increasing NH_4 in relation to NO_3 are hypothesized to reduce the competitive advantage of larger, fast growing algal forms, like diatoms, and selects for smaller, slower growing groups like flagellates, greens and cyanobacteria. The latter algal forms are identified as being of a lower nutritional value for some high-quality zooplankton herbivores resulting in a reduction in secondary production and "bottom up" ecological effects further up the food chain, including decreases in fishery production.

Studies conducted in the lab and field by numerous local researchers to examine these hypotheses have had conflicting results, and uncertainties regarding whether changes in phytoplankton composition are correct interpretations of monitoring data have entered the discussion (Cloern et al. 2014).

One or both of these hypotheses may explain past changes in algal abundance and species and help predict future changes based on an anticipated state change (i.e., a unidirectional, reduction in nitrogen and phosphorus loads, including a reduction in ammonia concentrations) in the system due to upgrades being made to the Regional San municipal wastewater treatment plant (serving much of the Sacramento area) and the City of Stockton municipal wastewater treatment plant. Decreases of total phosphorus and total nitrogen loadings are expected to occur due to permitted NPDES upgrades. This projected change in the loads of nutrients presents a potential opportunity to test the ammonia paradox and ecological stoichiometry hypotheses in the field. The workshop provides an opportunity for a panel of technical experts to review scientific literature, listen to researcher's presentations and then write a white paper that identifies recommended research strategies to evaluate the effects of this state change, along with additional studies that would help us resolve conflicting results.

Process

White Paper Development: The primary input to the white paper will be a 2-day workshop during which local researchers will present their findings on the ecological background of the Delta, anticipated state changes, and findings from research conducted on two nutrient-focused hypotheses. The white paper author and expert panel will actively participate in the workshop and will summarize: the main observations of the workshop presentations and reports; the discussions between panel members and presenters; and areas of agreement and disagreement based upon the presentations and reports submitted for the workshop. Using the workshop summary, additional literature, and the best professional judgment of the panel, the white paper author will develop a final document that: 1) describes what is known about the importance of nutrients (forms, ratios, concentrations, and loads) to the decrease in primary productivity and shifts in algal species composition in the Delta and Suisun Bay; 2) identifies significant unresolved science questions; and 3) provides recommendations for future research and monitoring.

Charge for the Workshop

The purpose of the workshop is to review studies involving the two nutrient hypotheses described above and summaries of the peer reviewed literature to determine areas of agreement and disagreement; identify the types of follow-up studies needed to resolve differences; and, provide recommendations for future research and monitoring.

The white paper author and panel will examine observations and evidence related to primary production and phytoplankton community composition (including physical, chemical, biological, and phytoplankton-physiological factors), both from field observations and controlled experiments, and report on the following:

1. Precisely articulate the areas/topics of certainty and uncertainty (observations, causal factors, specific mechanisms) within the scientific community regarding the relationships between nutrient forms, ratios, concentrations, and loads and the following in the Delta and Suisun Bay:
    a. Low production or low phytoplankton biomass
    b. Shifts in phytoplankton community composition

2. Identify the types of studies (e.g., field investigations, controlled experiments, statistical analysis of data, and modeling) that would test the areas of disagreement and outstanding science questions related to the following in the Delta and Suisun Bay:
    a. Low production or low phytoplankton biomass
    b. Shifts in phytoplankton community composition

3. Identify additional studies and monitoring needed to fill knowledge gaps and understand changes in phytoplankton species composition and biomass in the Delta and Suisun Bay, particularly in light of anticipated changes in nitrogen and ammonia loads.

Table 1 contains questions for the white paper author and panel members to consider as they participate in the workshop and develop the white paper. It is anticipated that the white paper author will refine these questions and, with input from panel members, help structure the overall workshop. The goal of the joint workshop is to move our understanding forward on the science with which to base management decisions on, so the following questions have been developed to facilitate that goal rather than focus on the conflicts between studies.

Table 1. Detailed Questions for the Workshop White Paper:

1. Can differences in experimental conditions (for example, light levels, temperature, duration of experiment, pH, salinity, grazing, initial experimental conditions, phytoplankton species and genetics, and others) explain different results from different researchers for the ammonia paradox hypothesis?

2. Can differences in experimental conditions (for example, light levels, temperature, duration of experiment, pH, salinity, grazing, initial experimental conditions, phytoplankton species and genetics, and others) explain different results from different researchers for the

ecological stoichiometry hypothesis?

3. What bench-scale/mesocosm/field experiments would test the ammonia paradox hypothesis in the Delta and in Suisun Bay? In controlled tests, what are the appropriate and ecologically relevant nutrient concentrations and ratios to use as experimental variables?

4. What bench-scale/mesocosm/field experiments would test the ecological stoichiometry hypothesis in the Delta and in Suisun Bay? In controlled tests, what are the appropriate and ecologically relevant nutrient concentrations and ratios to use as experimental variables?

5. What factors should be considered in the experimental designs:
   a. What are the appropriate and ecologically relevant temporal scales (hours, days, weeks) at which to evaluate the ammonia paradox and ecological stoichiometry hypotheses in the Delta?
   b. What is the duration and frequency of occurrence of the time frame where the ammonia paradox is believed to be important?
   c. What are the appropriate and ecologically relevant nutrient concentrations and ratios to use as experimental variables?
   d. What modeling or other work should precede the experiments to identify the nutrient concentrations and ratios that will result in situ from management actions underway?

6. What nutrient monitoring, special studies, and modeling are recommended to track changes in nutrient levels and phytoplankton responses in the Delta? Note that presenters will be asked to make predictions in their oral presentations based on their understanding of the mechanisms affecting phytoplankton abundance and species composition about how the Delta and Suisun Bay will respond to the expected nutrient state change and to describe experiments to test the predictions. The panel will review and comment on the appropriateness of both the predictions and experimental design.

7. What is the range of potential outcomes, regarding biological impacts, of future management in the Delta? In other words, what can reasonably be expected, in terms of phytoplankton abundance, biomass, species, composition, and what are the justifications for those predictions?

8. How does the Delta Estuary fit into the global spectrum of river-dominated estuary systems across multiple parameters? Based on its particular characteristics (e.g., habitat types, morphology, flow/tidal flux/retention time, light/turbidity, seasonal nutrient loads and forms and food web components), what can we anticipate about the Bay-Delta's responses, in comparison with responses to changes in nutrient loads observed in other estuaries?

Roles and Responsibilities

White Paper Author: Responsibilities for the white paper author are to provide advice on the organization and structure of the workshop including recommendation of panel members, refinement of questions both to support the final white paper and to presenters, and final selection of presenters, help develop the white paper outline, write

the white paper and present it to stakeholder and technical groups (maybe 2 web-based presentations), respond to comments and prepare the final document. The white paper should represent the consensus of the panel and, in areas where consensus is not reached, should reflect the diversity of opinions among panel members.

Panel: The panel will be comprised of four to six individuals with relevant scientific expertise. Panelists will be a combination of regional and outside experts. The role of the panel will be to discuss and evaluate workshop presentations and written material and to formulate a response to the charge questions with assistance from the white paper author.

Stakeholder Involvement: Members of the Delta and San Francisco Bay nutrient stakeholder advisory groups will participate in planning the workshop. It is also anticipated that members of the groups will attend the workshop. Upon completion of the draft white paper, the stakeholders will be given an opportunity to review and provide comments. The white paper will be revised to respond to their comments and questions.

Products

The process of reviewing and evaluating the role of nutrients in determining phytoplankton species and abundance will produce a set of products listed below.

- White paper outline
- Workshop summary [exact format to be determined with white paper author prior to workshop. Possibilities include detailed notes of workshop appended to white paper and/or autonomous workshop report.]
- Draft white paper
- Comments and recommendations from Delta and San Francisco Bay nutrient stakeholder advisory groups
- Final white paper with comments from the stakeholder advisory groups addressed

These products in combination with previously completed white papers and knowledge gap documents will be used by Central Valley Water Board staff and Delta stakeholders to develop a draft Delta Nutrient Research Plan. The draft Delta Nutrient Research Plan will be reviewed by Delta stakeholders and the State Water Board's nutrient objectives Independent Science Review Panel before being presented to the members of the Central Valley Water Board. Once the Research Plan has been implemented, Delta stakeholders will also be asked to review study results and subsequent recommendations as to whether water quality objectives for nutrients are needed in the Delta.

Draft Schedule

Workshop: April – June 2016
Draft Nutrient Research Plan available for review – November 2016
Nutrient Research Plan presented to Central Valley Water Board: February 2017

Citations

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

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Dugdale, R.C., F.P. Wilkerson, A.E. Parker, A. Marchi and K. Taberski. 2012. River flow and ammonium discharge determine spring phytoplankton blooms in an urbanized estuary. Estuarine and Coastal Shelf Science 115: 187-199.

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

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Meyer, JS, PJ Mulholland, HW Paerl, and AK Ward. 2009. A Framework for Research Addressing the Role of Ammonia/Ammonium in the Sacramento-San Joaquin Delta and the San Francisco Estuary Ecosystem. Prepared for the CALFED Science Program. http://www.science.calwater.ca.gov/pdf/workshops/workshop_ammonia_research_framework_final_041609.pdf