Comments for Consideration by the State Water Resources Control Board Regarding *Long-term Changes in Nutrient Loading and Stochiometry and their Relationships with Changes in the Food Web and Dominant Pelagic Fish Species in the San Francisco Estuary, California* by Patricia Glibert - pre-print copy (May 17th, 2010).

PREPARED FOR: Stan Dean/SRCSD
Linda Dorn/SRCSD
Jason Lofton/SRCSD
Terrie Mitchell/SRCSD

PREPARED BY: Cameron Irvine/CH2M HILL
Earl Byron/CH2M HILL
Larry Hilscher/CH2M HILL

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A peer-reviewed paper by Dr. Patricia Glibert describes the relationships over time between nutrients (primarily ammonium, nitrate, and phosphorus) and the Delta food web (algae, zooplankton and POD fishes). This paper has been accepted by the journal *Reviews in Fisheries Science* and a pre-print copy was distributed by Dr Glibert's Center for Environmental Science at the University of Maryland. Comments describing the findings of this paper that relate to the Sacramento Regional Wastewater Treatment Plant (SRWTP) are provided below based on a limited review of the report because all of the supporting data were unavailable. Several issues and questions were identified during this review and the major topics are presented below. However, the subject of relationships between various physicochemical parameters and fish populations or phytoplankton community composition is complex and additional effort and evaluation would be needed to help to clarify and tease out the answers to some of these questions.

General Comments

This paper presents a broad analysis of closely inter-correlated and auto-correlated variables (e.g., concentrations and flows are not independent) with an emphasis on time-series analysis. There are no direct comparisons (regressions or correlations) among parameters. Rather, the various parameters evaluated in this paper are compared indirectly through their variation from the average (i.e., increasing or decreasing trends) using the novel application of a statistical method used for control chart analyses. The cumulative sum (CUSUM) approach as applied to time series data is specifically designed to help elucidate the points in time where changes have most likely occurred. It is a cumulative sum of differences between the running average and a given point in the data set. The author is correct that the CUSUM method shows inflection points; however, the technique does not infer causality. Instead, it merely suggests possible relationships that may merit further evaluation using other statistical approaches. The underlying relationships also need to be interpreted based on an understanding of the biological mechanisms at work, as indicated on page 12 (292-294).

The author recognizes that the Delta is a complex system (lines 205-206) but then fails to address many of the key factors associated with this complexity in her analysis (e.g., water clarity and temperature; lines 504-507). She further assumes that the mechanisms underlying the associations are understood and does not consider alternative possibilities. Her presentation of the Delta ecosystem is over simplistic. The Delta, as is any large ecosystem, is quite complex. As a result, the conclusions of the article exceed the evidence presented. By taking such a broad approach to the problem, the author has been able to selectively present data that seem to support the primary hypothesis that smelt are not influenced by flows (as inappropriately estimated by X2 position) but are strongly influenced by ammonium discharge (i.e., loads, and to a lesser degree by ambient ammonium concentrations).

To suggest that "a clear management strategy is the regulation of effluent N discharge through nitrification and denitrification." (lines 715-716) is not demonstrated by the data presented. Many would argue that the delta is not eutrophic, and that reducing nutrients would further reduce primary productivity.

The paper concludes by saying "Until such [nitrogen] reductions occur, other measures, including regulation of water pumping or manipulations of salinity, mass has been the current strategy, will likely show little beneficial effect. Without such action, the recovery of the endangered pelagic fish species is unlikely at best" (lines 716-718). The introduction also claims that there is a "high probability for success in restoring endangered pelagic fish." However, the confidence in any single environmental management decision to have a strong positive impact on the Delta is never high. At best, resource managers will have moderate confidence in any decision, because our understanding of the Delta processes with existing data are insufficient. For the author to claim that there is high confidence in a single resource management decision is not supported.

Specific Comments

Statistical Approach

- The author presents a relatively novel approach to analyze time-series data. There is nothing inherently wrong with this approach for identifying inflection points and for making limited interpretations, but the **conclusions assume a broad understanding of the Delta ecosystem and her interpretations are dependent on many assumptions.**

- A typical goal when applying CUSUM values to a time series is to quickly detect a change in the process mean (such as when applying the CUSUM values in a control chart). By keeping a cumulative total of deviations from the process mean, this approach to temporal monitoring offers one method that may reveal small shifts in the data that might otherwise have been undetected. When evaluating these transformed CUSUM values, one typically seeks to determine if a substantial upward or downward trend develops in the plotted points.

- The application of CUSUM values in this report, however, goes beyond merely identifying temporal periods where an upward or downward trend occurs. CUSUM values were used to make correlations between various parameters. Such applications of CUSUM values may promote a greater focus on the impact of shifts in the parameters than on the actual magnitude of the values at any given time (or even the magnitude of values adjusted by some lag time to allow one parameter time to influence another). Whether this is a prudent approach is not clear. The author has not appeared to reference previous accepted applications of this correlation component of the approach (other than a single reference to another of her publications – in press). Thus, it is difficult to gauge the efficacy of using correlations between CUSUM values to understand relationships between parameters and **conclusions based on this novel statistical approach should be viewed with caution.**

- Correlation evaluations of raw data, lag-time adjusted data, etc. would help to offer alternative insights of the available data or help to infer causality. Therefore, alternative approaches and evaluations of the data are needed to fully evaluate the efficacy of the data analyses presented by Glibert.

- The literature describing CUSUM analysis does not appear to support or refute the statement that "The effect of such manipulation [summing CUSUM scores over time] is to filter the short term or seasonal variance, thereby revealing the long-term patterns in the data." **Whether CUSUM analysis serves to filter short-term variance and reveal long-term patterns is a novel interpretation of this analytical tool that is untested and has not been verified.** This claim, as it applies to the type of evaluation used in this manuscript, should be documented with references to other studies that have successfully used it. Otherwise, some of the conclusive statements in the report would appear to more appropriately slip into a language of unsettled hypotheses. A copy of the cited Glibert et al. (in review) may provide additional information about this approach, but was not available for review.

- Wastewater ammonium loads have shown steady increases over time that correlate with population increases in Sacramento County (Jassby 2008). Because CUSUMs are sensitive to the time period and average concentration that occurs during the selected period, it may be possible to identify different inflection points and make different interpretations using other timeframes. However, **any variables that have shown monotonic trends over recent years will, by definition, show positive CUSUM relationships to ammonium loading. Causality of the association cannot be inferred.**

Confidence in Conclusions and Recommended Actions

- **The confidence in conclusions and management decisions is overstated.** The author expresses very high confidence that the results of this analysis accurately explain the cause of the POD and that the recommended resource management decisions (i.e., nitrification and denitrification at SRWTP) will solve the POD (e.g., lines 595-597). The perception that we understand the Delta sufficiently to have such confidence in the results from any one simple analysis based on limited data, or that such simple management decisions could address such a complex issue, suggests an over simplistic conceptual model of the Delta. Conclusions regarding the function of ecosystems are typically stated more cautiously, and resource management decisions affecting large and complex ecosystems, in general, can never be made with 'high' confidence.

Limited Data

- **Few stations are evaluated when there are available data from many more.** The Delta has many monitoring stations and it is known that processes are not the same among all of them. For example, Parker et al. (2010) reported that algae in the Sacramento River respond differently to ammonium than algae in Suisun Bay (Dugdale et al. 2007). It is unclear whether data from the small selection of stations presented are representative of others in different areas of the Delta.

- **This analysis does not fully consider many factors that are considered important drivers in the POD, such as turbidity, *Microcystis*, Delta exports, contaminants, and invasive species (i.e., bivalves).** The absence of data evaluations for parameters that have been hypothesized and described by others as potentially important factors affecting the Delta food web adds significant uncertainty to the confidence in Glibert's conclusions that only ammonium has affected the Delta ecosystem. .

    - Turbidity has declined significantly over the past 30 years as flows have been controlled, submerged aquatic vegetation densities have increased, and bivalve densities have increased. Delta smelt respond directly to changes in turbidity (they prefer turbid waters where they are less likely to be eaten by predators) and there is a correlation between reduced turbidity and reduced delta smelt, yet this parameter is not considered in the Glibert analysis.

    - *Microcysis*, a blue-green algae (cyanobacteria) responsible for harmful algae blooms, has increased in recent years. Lehman (2008) conducted multivariate statistical analyses of multiple parameters potentially affecting Delta cyanobacteria and found that nutrients are not a driver for these harmful algae blooms, but flow has a significant influence. Recent data by Mioni (2010) supports the findings of Lehman. Despite referencing the Lehman (2008) paper, findings suggesting the influence of flow on harmful algae blooms are not mentioned in the Glibert paper (lines 559-561). Moreover, a reference to Lehman (2010) supports the ecological effects that cyanobacteria have on algae, zooplankton, and fish communities; although, Glibert again neglects to point out the influence of flow described therein.

    - Delta Exports have direct effects on fish survival/entrainment and algae losses that are not considered in this paper. Only delta flows and X2 are evaluated – which are measures of flow as waters exit the Delta - while exports are not considered in the analysis of possible contributors to the POD. Therefore, conclusions that claim to identify potential causes of the POD are incomplete. Glibert states that "changes in flow are not correlated with all nutrients and nutrient ratios over the entire time series…although there were significant, but different, relationships for the pre-POD and POD years." (lines 597-599; Figure 8). Similar comparisons to should be presented for other parameters (i.e., exports and fish, exports and phytoplankton abundance, flows and clam abundance, etc.) to complete the analyses.

- There is no consideration of the possible effects of contaminants on the POD**.** Recent studies indicate that the use of pyrethroid insecticides have resulted in ambient surface water concentrations that are toxic to sensitive invertebrates. Since the use of pyrethroids co-occurs with the POD (post-2000) there is reason to suspect that they have contributed to Delta ecosystem changes, yet they are not considered in the Glibert paper.

- Invasive clams have been the subject of compelling arguments showing their devastating impacts on Delta plankton (i.e., Kimmerer 1994). The potential influence, or relative proportion of these effects, is dismissed by Glibert despite the well understood ecological relationships supporting the role of invasive clams in reducing plankton. A statement (lines 445-446) claims that there were "no significant relationships between CUSUM trends in fish or clam abundance and the CUSUM of X2 (Table 1)." The analyses are incomplete without comparisons between clam abundance and fish abundance, or clam abundance and plankton abundance.

- **Ammonium trends in the San Joaquin River should be further evaluated and compared to Delta biota rather than ignored because they show trends that differ from those in the Sacramento River and Suisun Bay.** San Joaquin ammonium concentrations were relatively constant over time and decreased after 2000. This trend differs from the increasing trends in the Sacramento River and Suisun Bay (Figure 3; lines 328-332). The difference is used to support the hypothesis that the Sacramento River dominates the system and exclude any further analysis of the data from the Jan Joaquin River station. However, this difference should be used to evaluate plankton responses to ammonium in another part of the Delta and as a test case for the effects of nutrient removal (i.e., at the Stockton WWTP). The lack of further data analysis from the San Joaquin station is a potentially significant data gap.

- **It is surprising that large changes in fish, zooplankton, and algae can be attributed to very small changes in ammonium** (generally from 0.2 to 0.4 mg/L over 30 years) (Figure 3). The methods for data selection or data reduction is not entirely clear, since there are many more data points in Figure 3 than are presented in subsequent Figures. How the data are truncated (e.g., annual or monthly averages) should be explained and must make ecological sense. Plankton respond to local conditions on the timeframe of days to weeks. If comparisons are being made with annual averages it increases the uncertainty associated with any conclusions. These uncertainties should to be discussed.

Assumed Relationships

- **Aquatic organisms respond to concentrations and not to loads (i.e., kg/day) or to trends.** Conclusions that ammonium has caused the POD are heavily weighted by comparisons between ammonium loading or effluent concentrations (441-444 and 579-582; Figure 6 and 22) and aquatic resources (i.e., algae, zooplankton, and fish). There is a fundamental problem with this concept, since aquatic organisms respond to concentrations, and any relationships assumed to exist between nutrient loading from SRWTP and plankton or fish are inappropriate.
    - The assumed relationship between loads and effects is clearly stated in the discussion: "The decline in diatoms, which began in 1982, was highly correlated with the increase in NH4 loading." Many of the comments above apply to this statement (i.e., organisms respond to concentrations and not loads, other factors such as invasive clams significantly affected the phytoplankton communities in the mid-1980s, one station does not tell the story for the entire Delta. Despite what may appear to be similar trends between ammonium and algae it seems unlikely that the relatively small change in ammonium concentrations would have such a large impact.
    - Likewise, **ammonium concentrations in SRWTP effluent is not a surrogate for concentrations in the receiving water** (Figure 7 and 22), or in any part of the Delta where algae or fish are found. SRWTP effluent is diluted significantly by river flows and ambient concentrations are therefore dependent on those flows.
    - **Time lags between nutrients and algae and algae and zooplankton may be particularly important in determining causal relationships but are unexamined in this study**.
- POD species do not occur exclusively in Suisun Bay. Therefore, it is assumed that any relationships found between concentrations and responses in Suisun Bay also apply to the entire Delta. Existing data from Parker et al. (2010) show that this assumption is not true for phytoplankton responses to ammonium between Suisun Bay and the Sacramento River.
- **Step changes in phytoplankton that correspond with invasive clams in the mid 1980's are disregarded** in favor of a suggested "causation" due to similarly timed, but relatively small increases in ammonium (lines 534-536, 710-712). Glibert states that clams thrived because of nutrient loading, citing a correlation between the CUSUM of NH4 (location not indicated) and the CUSUM of clam abundance. Correlation does not mean causation, as the author recognizes in the methods section. It is uncertain whether a correlation between trends (as indicated by correlating CUSUM values) has any environmental relevance. The correlation between invasive clam appearing in the Delta in 1986-1987 and a step decline in algae abundance (apparent in Figure 9a) has been reported by others as a clear cause and effect relationship that is not considered a possible contributor to the POD in Glibert's analysis.

  - Likewise, a discussion of similar CUSUM trends between phytoplankton and NH4 (lines 374-390; figure 10) focuses on data after 1984 when SRWTP began discharging combined treated wastewater for much of Sacramento County, but does not consider the effects of invasive clam grazing on phytoplankton in Suisun Bay that also began in 1987.

- **It is challenging to track the data presented among these figures and there appear to be inconsistencies that are not explained.** For example, CUSUM values for NH4 at station D8 (Suisun Bay) are shown in Figure 3B and range from +30 to -30. Figures 20 and 21 show regressions between CUSUMs for fish abundance and nutrients (NH4 and DIN:DIP). These nutrient data are said to be Station D8 (Suisun Bay), but the range of CUSUM values is only from -8 to 0, which do not correspond with the range of CUSUM values at Station D8. Likewise, CUSUM values for NH4 are shown in figure 14 (comparison with CUSUM for Corbicula abundance) also only range from -8 to 0, and are inconsistent with the ambient data. However, the range of CUSUM values presented in these figures corresponds with the range of CUSUM values for NH4 in wastewater discharge that are shown in Figure 22. These inconsistencies in the presented data need to be explained or corrected and may have significant impacts on the conclusions if relationships are based on loads and effluent concentrations and not ambient concentrations.

- **The response of delta smelt is emphasized over other fish with similar diets (plankton) that have opposite CUSUM responses over time.** Although the delta smelt and longfin smelt declines may support some kind of correlation between abundance CUSUMs and ammonium CUSUMs over time (Figure 20), largemouth bass, inland silversides, threadfin shad, and sunfish show stronger responses to the contrary (lines 419-434; Figure 21). Diets are generally considered similar among these POD species, but more detailed analysis is needed to tease out potential causal relationships. However, Glibert presents CUSUM analyses that are intended to suggest that these differences among fish species are related to changes in specific zooplankton species abundance (Figures 18 and 19). The degree of independence among these datasets is not clear when other factors (e.g., export flows) could be driving relationships. Further data evaluation is suggested to clarify the various related factors and their relative influences.

- **It is conceptually flawed to conclude that correlations between NH4 concentrations in Suisun Bay and algae concentrations became more pronounced <u>because</u> the SRWTP came online in the mid 1980's** (lines 385-390). This temporal dissociation between pre- and post-SRWTP discharge is unfounded. Ammonium was constantly discharged into the Delta from multiple WWTPs prior to SRWTP combining many of these separate flows into one treatment facility and a single discharge point. The ammonium loads in treated wastewater are associated with population increases and not with operational changes.

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