Factors Controlling Submersed and Floating Macrophytes in the Sacramento-San Joaquin Delta

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and
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EXECUTIVE SUMMARY

The Central Valley Regional Water Quality Control Board (Water Board) is developing a plan to generate the science needed to support decisions on policies governing nutrient management in the Delta. Non-native, invasive floating and submersed aquatic vegetation (SAV) is one of three areas, identified by Water Board, that represent pathways of potential ecosystem impairment that could be linked to nutrients. The Water Board commissioned a literature review of the factors that may be controlling the prevalence of floating and SAV. This literature review addresses three major questions:

1) How do submersed and floating aquatic vegetation support or adversely effect ecosystem services and related beneficial uses?
2) What is known about the spatial and temporal trends in submersed and floating aquatic vegetation in the Delta?
3) What is the relative importance of nutrients versus other factors in promoting observed trends in submersed and floating aquatic vegetation in the Delta?

This review had seven major findings:

#1. Submersed and floating vegetation can be beneficial components of the Delta; however, several non-native species have been found to adversely affect Delta ecosystem services and associated beneficial uses at the high densities at which they typically occur. Adverse effects include: (1) changes to water chemistry, including diurnal swings in pH and dissolved oxygen, (2) changes to physical properties of water, including flow and turbidity, (3) outcompetition of native SAV, phytoplankton, and other benthic primary producers, (3) changes to the food web, (4) impedance of navigation and obstruction of water conveyance, and (5) poor aesthetics.

#2. Two invasive species, *Egeria densa* (Brazilian waterweed, a submersed species) and *Eichhornia crassipes* (water hyacinth, a floating species), are widely recognized as problematic in the Delta, and appear to be increasing in abundance despite control efforts. *E. densa* coverage was estimated at ~2,000 hectares in 2007, and 2,900 hectares in 2014. *E. crassipes* covered ~200 hectares between 2004 and 2008, and 800 hectares in 2014.

#3. Additional invaders may also have reached high enough abundance to be considered problematic, especially *Ludwigia* spp. (water primrose). *Ludwigia* spp. (unknown proportion of *L. peploides* and *L. hexapetala*, and possibly *L. grandiflora*) are now equal in floating coverage to water hyacinth (800 hectares each, estimated in 2014), whereas the native pennywort was much more common than *Ludwigia* during the period of 2004-2008. *Ludwigia* spp. are not part of a control program in the Delta at this time.

#4. Data on spatial and temporal trends in invasive aquatic plants have been collected only sporadically in space and time and without adequate detail. Remote sensing may be adequate to estimate coverage of floating vegetation, but submersed vegetation requires a much greater, field-based effort to distinguish species. Both types of vegetation require estimates of biomass or, preferably, primary production if we are to understand patterns in abundance and rates of turnover.

#5. Existing scientific literature has documented a number of environmental and management-related factors that have control over the growth of invasive aquatic plants worldwide. These include: (1) light, (2) temperature, (3) salinity, (4) dissolved inorganic carbon (for SAV), (5) nutrients, (6) flow and residence time, (7) interaction with other species, and (8) control efforts.

#6. Studies have documented the importance of a subset of environmental factors in the Delta, but insufficient evidence exists to determine the relative importance of nutrients versus other factors in promoting the expansion of these species. Drawing on available information, we can conclude the following:

- Conditions in the Delta, including seasonal low flow, low turbidity, warm temperatures, and a freshwater (low salinity) regime, appear to favor the establishment and growth of invasive macrophytes.
- Aquatic plants require macronutrients (nitrogen, N, and phosphorus, P) for growth. N and P are available in relatively high concentrations in the Delta (~0.5 mg l^{-1} dissolved inorganic N, DIN, and 0.06 mg l^{-1} DIP), and available nutrients may not limit growth. However, it is difficult to discern the relative influence of nutrients versus other factors, making uncertain the effect that nutrient management could have on growth and persistence of these invasive aquatic plants. Recent rapid expansion of invasive macrophyte acreage, despite evidence that concentrations of NH_4^+, NO_3^-, PO_4^+, and ratios of N:P within Delta waters have been steady over the last decade, suggests other factors besides nutrients are contributing to the extensive plant growth at the scale of the whole Delta.

#7. Climate change and anthropogenic activity associated with land use changes have the potential to further increase the prevalence of invasive macrophytes. Climate change will likely result in warmer temperatures, reduced frequency of frost, and increased drought, the last of which could result in reduced flows and increased residence time in the Delta. These factors would provide a favorable environment for increased prevalence of *E. densa* and *E. crassipes* and, perhaps, other invaders. However, increased salinity intrusion into the west Delta would favor native species of aquatic vegetation – in particular, the pondweed *Stuckenia pectinata*.

Given these findings, three major science recommendations are proposed:

R1: Implement routine monitoring of invasive floating and submersed aquatic vegetation. Routine monitoring of floating and submersed aquatic vegetation should be undertaken to assess trends over time and to support ecosystem modeling of the Delta. Grant-funded efforts have been sporadic, and there is no plan for ongoing rigorous evaluation of patterns and trends. Monitoring should be comprised of a combination of remotely sensed areal coverage and field-based measures to estimate biomass or, ideally, net primary production (through repeated measures of biomass over time to determine rates of turnover), as well as species composition. Estimates of biomass/production and areal cover should be conducted in combination with measures of the major factors that control growth of these primary producers, including water column and sediment nutrients and other standard water quality measures (e.g., temperature, salinity, pH, dissolved oxygen), as well as flow rates. Early actions should include the development of a work plan to lay out the key indicators and cost estimates required for monitoring.

R2: Develop a biogeochemical model of the Delta, focused on nutrient and organic carbon fate and transport. Understanding of factors controlling floating and SAV is critically hampered by the lack of information on nutrient and carbon budgets for the Delta and its subregions. In particular, it is important to quantify the storage in the compartments of the ecosystem (i.e. water, sediment, plant biomass, etc.) and fluxes or exchanges between compartments at varying seasonal and spatial scales and with a variety of water flow and residence time scenarios. This information will provide an understanding of whether management of nutrients is likely to aid in control of floating and SAV. To step into model development, three actions should be taken: (1) examine existing models already available to determine suitability for this task, (2) develop a work plan that lays out the modeling strategy, model data requirements, and implementation strategy, and (3) conduct special studies and other monitoring needed to support model development. This includes special studies that quantify N, P, and organic carbon associated with ecosystem compartments, as well as uptake, release and flux rates that characterize different reaches of the Delta. Lab and field experiments that test whether macrophyte growth is limited by nutrients in Delta waters could help inform management and predict problem areas. These analyses and experiments should inform hypotheses that can be tested through model development, as well as potential future scenarios. The monitoring and modeling teams should collaborate closely to collect high-priority data to inform the models.

R3. Review current and potential future control strategies for invasive aquatic macrophytes in the Delta, including mechanical, chemical, biological control, and integrated control methods, as well as barriers that reduce movement of vegetation into sensitive areas or those with heavy human use. Depending on the outcome of R2, nutrient management may be ineffective in controlling invasive floating and SAV. While monitoring, modeling and special studies are underway, this review should determine the degree to which control strategies are supporting beneficial uses and nutrient management objectives going forward. This work should begin by evaluating current and planned control strategies to determine effectiveness at both reducing live biomass and minimizing recycling of nutrients from the sediments into additional growth. A current USDA-ARS program on integrated control methods for both *E. densa* and *E. crassipes* could help inform the proposed review.