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

Prepared for:

The Central Valley Regional Water Quality Control Board

And

The California Environmental Protection Agency

State Water Resources Control Board

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Katharyn Boyer

Romberg Tiburon Center for Environmental Studies

San Francisco State University

Martha Sutula

Southern California Coastal

Water Research Project

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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) are 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. Native submersed and floating vegetation are beneficial components of the Delta; however, 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) impedence of navigation and obstruction of industrial intake pipes 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 ~2000 hectares in 2007 and 2900 hectares in 2014. *E. crassipes* covered ~200 hectares between 2004-2008 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 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 of 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 these 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 0.05 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, suggest 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 latter of which could result in reduced flows, increased residence time and water column stability 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 on-going rigorous evaluation of patterns and trends. Monitoring should be comprised of a combination of remotely sensed areal coverage and field-based transects 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. Early actions should include the development of a workplan 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.

Comment [KB1]: Point of discussion: John Madsen said "the authors are assuming that nutrients are limiting plant growth without knowing this. It is doubtful that an ecosystem model will indicate if nutrients are limiting either water hy or egeria. It is far more common to see luxury consumption of nutrietns by submersed and floating aquatic plants than nutrient limitation".

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 under way, 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 dead material into additional growth in areas with high residence time. A current USDA-ARS progam on integrated control methods for both *E. densa* and *E. crassipes* could help to inform the proposed review.

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1.1 Background and Context

The Sacramento–San Joaquin River Delta (hereto referred to as "the Delta"), is an inland river delta and estuary approximately 1300 square miles in size, found in Northern California (Fig. 1.1). Formed at the western edge of the Central Valley by the confluence of the Sacramento and San Joaquin Rivers, the Delta is a key component of the State's water resource infrastructure and a region that is rapidly urbanizing, yet serves as critical habitat for fish, birds and wildlife. Water from the 45,000 square miles of Delta watershed fuels both local and statewide economies, including important agricultural commodities. The Delta is widely recognized as being in a state of "crisis" because of competing demands for the Delta's resources (Delta Plan 2013). The consequences of these competing demands include point and non-point discharges, habitat fragmentation and loss, modified flow regimes, introduction of non-native species, all of which combine to threaten ecosystem health, including the continued decline of native fish (Delta Plan 2013).

In 2009 the California legislature passed the Delta Reform Act creating the Delta Stewardship Council. The mission of the Council is to implement the coequal goals of the Reform Act and provide a more reliable water supply for California while protecting, restoring, and enhancing the Delta ecosystem. The Council wrote and adopted a Delta Plan in 2013 to implement these goals. Chapter 6 of the Delta Plan deals with water quality and contains recommendations to implement the coequal goals of the Delta Reform Act. Among these include a recommendation to consider development of nutrient objectives for the Delta.

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

1. Decreases in phytoplankton abundance and shifts in algal species composition,

2. Increases in the abundance and distribution of macrophytes, including water hyacinth and Brazilian waterweed, and

3. Increases in the magnitude and frequency of cyanobacterial blooms

To provide better scientific grounding for the study plan, the Water Board commissioned two literature reviews centered on the latter two potential areas of impairment. This document provides a synthesis of literature on submersed and floating macrophytes in the Delta.

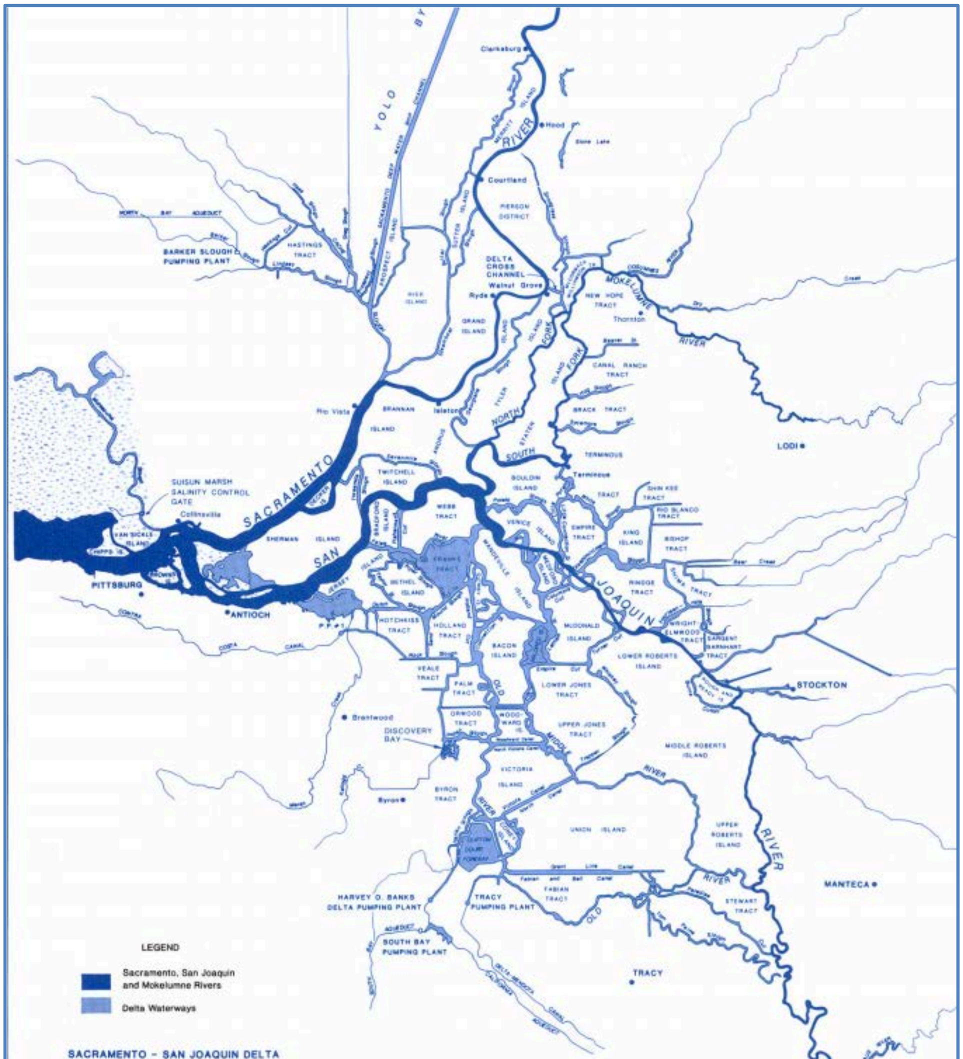

Figure 1.1 The Sacramento-San Joaquin Delta Region

Comment [KB2]: Consider replacing figure – Shruti said hard to read (and I agree). What was ultimately used in the cyano review?

1.2 Goal and Organization of Macrophyte Literature Review

This review aims to assess whether there is evidence that the perceived increase in the abundance and distribution of submersed or floating aquatic macrophytes in the Delta is the result of long term changes in nutrient or organic matter loading relative to other factors and to ascertain whether management of nutrient loads might be used to remedy the problems associated with these macrophytes. This review will be evaluated and utilized by a Science Working Group to develop recommendations for a research plan to resolve outstanding questions regarding the need for nutrient management to reduce the impacts of invasive aquatic macrophyte species; a Stakeholder and Technical Advisory Group (STAG) will review and contribute to the research plan.

This review addresses the following key 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?
4) What are the key data gaps and recommended future studies?

The document is organized as follows:

Section 1: Introduction, Purpose and Organization of the Review

Section 2: General Ecology and Trends in the Distribution of Submersed and Floating Aquatic Vegetation in the Delta

Section 3: Role of Submersed and Floating Aquatic Vegetation in Supporting Ecosystem Services

Section 4: Factors Contributing to the Prevalence of Submersed and Floating Aquatic Vegetation in the Delta

Section 5: Recommendations

Section 6: Literature Cited

2. General Ecology and Trends in the Distribution of Submersed and Floating Aquatic Vegetation in the Delta

2.1 Classification of Aquatic Vegetation and Scope of Review

This review pertains to the fully aquatic vegetation in the Delta, including those submersed and rooted plant species in the sediments and those floating on the surface. It does not include emergent species such as sedges, rushes, and broad-leafed forbs that are rooted along the Delta's shores but do not extend across the water surface beyond where they are rooted. The focus is on the most common species and especially the prolific invaders for which management measures leading to a reduction in abundance and distribution, if feasible, would be deemed acceptable and desirable to resource agencies, scientists, and the general public. We consider only the vascular plants; macro- and microalgae are outside of the scope of this review, although they are mentioned in terms of macrophyte effects on them.

2.2 Overview of Species Found in the Delta

There are at least nineteen species of submersed or floating aquatic plants in the Delta (Table 2.1) as identified in the peer-reviewed and grey literature (Anderson 1990, 2011; Jassby and Cloern 2000; Ustin et al. 2007, 2008; Santos et al. 2011; Khanna et al. 2012, Khanna, pers. comm. 2015; Boyer et al. 2012, 2013; Cohen et al. 2014). About half of those species are rooted and submersed beneath the water surface except at low tides. Roughly half of the species are introductions from other regions.

No studies have estimated abundance of all these species Delta-wide, but patterns in relative abundance have been evaluated within particular regions. Two studies focused on submersed species (Santos et al. 2011; Boyer et al. 2013) used a rake method in which the number of tines occupied by each species is used to determine relative abundance (Kenow et al. 2007). *Egeria densa* was by far the most abundant submersed species found in the central Delta study, with detections at 70-90% of sampling points (Santos et al. 2011; Fig. 2.1). Similarly, *E. densa* was detected up to 100% of the time within the submersed vegetation beds sampled at four west Delta locations (Boyer et al. 2013; Fig. 2.2). Recent remote sensing data indicate that submersed vegetation covers ~2900 hectares of the Delta, with *E. densa* dominant among the species (Khanna and Ustin 2014, unpublished data; CA State Parks Division of Boating and Waterways [DBW]). Other submersed, non-native species are typically much less abundant (Fig. 2.1, 2.2), but both *Potamogeton crispus* and *Myriophyllum spicatum* are species of potential concern (see Santos et al. 2011). Distinguishing among submersed species in mixed stands is problematic, leading to concerns about accuracy of coverage estimates, as further discussed below.

Ceratophyllum demersum (coontail) was the most frequently encountered submersed native species within both the central and west Delta studies described above, and was more common than all the introduced species other than *E. densa* (Fig. 2.1, Santos et al. 2011; Fig. 2.2, Boyer et al. 2013). In the same central Delta region that harbored 383 hectares of *E. densa* in fall 2007, *C. demersum* covered 284 hectares (Santos et al. 2011; Fig. 2.1). In 2014, *C. demersum* was found in 45% of all sampled points for submersed aquatic vegetation with an average cover of 30% (Khanna and Ustin, unpublished data). We know of no Delta-wide estimates of acreage for this species.

Table 2.1. Submersed and floating vegetation in the Sacramento-San Joaquin Delta. N = Native, I = Introduced. * Indicates the most abundant introduced and native species, on which this review is focused.

Species	Common name	Submersed/ Floating	N/I
Cabomba caroliniana	Carolina fanwort	Submersed	I
*Egeria densa**	Brazilian waterweed	Submersed[1]	I
*Eichhornia crassipes**	Water hyacinth	Floating	I
Limnobium laevigatum	South American sponge plant	Floating	I
*Ludwigia hexapetala**	Uruguay water primrose	Floating	I
*Ludwigia peploides**	Water primrose	Floating	I[2]
Myriophyllum aquaticum	Parrot's feather	Floating	I
Myriophyllum spicatum	Eurasian watermilfoil	Submersed	I
Potamogeton crispus	Crisped or curly-leaf pondweed	Submersed	I
Azolla sp.	Water fern	Floating	N
*Ceratophyllum demersum**	Coontail	Submersed [3]	N
Elodea canadensis	Common waterweed	Submersed	N
*Hydrocotyle umbellata**	Pennywort	Floating	N
Lemna sp.	Duckweed	Floating	N
Ludwigia palustris	Water purslane	Floating	N
Potamogeton foliosus	Leafy pondweed	Submersed	N
Potamogeton nodosus	Long-leaf or American pondweed	Submersed[4]	N
Ruppia maritima	Widgeongrass	Submersed	N
*Stuckenia pectinata**	Sago pondweed	Submersed	N

1 *E. densa* is typically rooted but fragments can form floating mats.
2 There is confusion over the identification of native and non-native species of water primrose; this species has been designated as introduced in this review as it has by other authors (e.g., Khanna et al. 2012).
3 *C. demersum* is the one submersed species that is not rooted in the sediment; it is found loose in the water column.
4 *P. nodous* is rooted in the sediment but its leaves float at the surface of the water.

In addition, the native submersed pondweed *Stuckenia pectinata* was relatively common in the Delta sites (Fig. 2.1, Santos et al. 2011) and is typically the only aquatic plant species found within the open Suisun Bay (Fig. 2.2; Boyer et al. 2012, 2013). Although this species has been referred to as *S. filiformis* based on gross morphology, or *Stuckenia* spp. because of difficulty in identification, recent genetic analyses indicate *S. pectinata* is the correct species identification for a morphologically broad range of samples throughout Suisun Bay and the Delta (Patten and Boyer, unpublished; see below). Because *S. pectinata* occurs in monotypic stands in the open Suisun Bay and the plants are clearly visible from the surface of the water during summer low tides, Google Earth images show the beds well; these were digitized and systematically ground-truthed by boat and were found to very accurately represent the acreage present (Boyer et al. 2012). Approximately 200 hectares occur within Suisun Bay as determined through this digitizing and ground-truthing activity during 2011-2014 (Boyer et al. 2012, 2015). Such methodology could be effective in open water, high flow regions of the Delta as well, as *S. pectinata* occurs there at 100% relative abundance (Khanna, pers. comm., based on 2014 remote sensing and ground truthing). Estimating acreage remotely becomes much more difficult in semi-enclosed flooded islands and other embayments within the Delta where many more species are present; however, a rough estimate is that another 350 hectares of *S. pectinata* occur within the Delta region (Boyer et al. 2015). *S. pectinata* occurring in island interior sloughs and in Suisun Marsh is not included in these estimates.

Comment [KB3]: Ask Shruti if she can give an estimate

In terms of floating species, *Eichhornia crassipes* (water hyacinth) has become notorious for its role in clogging channels, marinas, and water supply pipes within the Delta (see Literature Cited, Local and Regional Press Reports, for many recent articles centered around the Stockton area). Worldwide, it is ranked as one of the worst invaders (OTA 1993). As of 2014 it covers ~800 hectares, based on remote sensing and ground truthing of point locations (Khanna and Ustin, unpublished). Its prevalence and nuisance effects in areas of high human activity have led to high interest in understanding factors that control it.

Number of detections, relative frequency (in percent) from point samples, area (ha) and percent cover of the submersed aquatic plant species detected in the Sacramento-San Joaquin River Delta (waterways area is 639.89 ha)

Scientific name	Code	Status	Fall 2007			Summer 2008		
			Detections (%)	Area (ha)	% cover	Detections (%)	Area (ha)	% cover
Egeria densa	EGDE	Non-native	339 (89)	382.49	59.77	300 (69)	99.64	15.6
Cabomba caroliniana	CACA	Non-native	1 (0.3)	NA	NA	36 (8)	1.41	0.2
Myriophyllum spicatum	MYSP	Non-native	32 (8)	68.03	10.6	78 (18)	20.4	3.2
Potamogeton crispus	POCR	Non-native	52 (14)	50.8	7.9	53 (12)	10.03	1.6
Total			424	382.9	59.8	467	174.08	27.2
Ceratophyllum demersum	CEDE	Native	107 (28)	283.77	44.3	180 (41)	59.14	9.2
Potamogeton nodosus	PONO	Native	1 (0.3)	NA	NA	10 (2)	6.04	0.9
Elodea canadensis	ELCA	Native	19 (5)	34.28	5.36	10 (2)	18.29	2.9
Stuckenia spp.	STSPP	Native	24 (6)	73.02	11.4	32 (7)	69.84	10.9
Total			151	294.29	45.9	232	157.04	24.5
Total submersed species			575	388.35	60.7	699	239.6	37.4


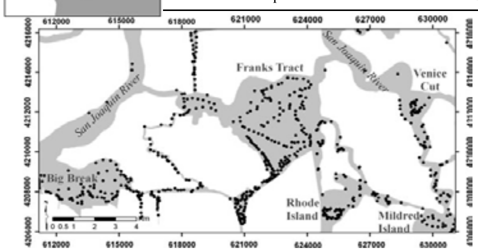

Figure. 2.1. Rake detections and other data on abundance of submersed species at sampling points within the central Delta (left). Excerpted from Santos et al. 2011

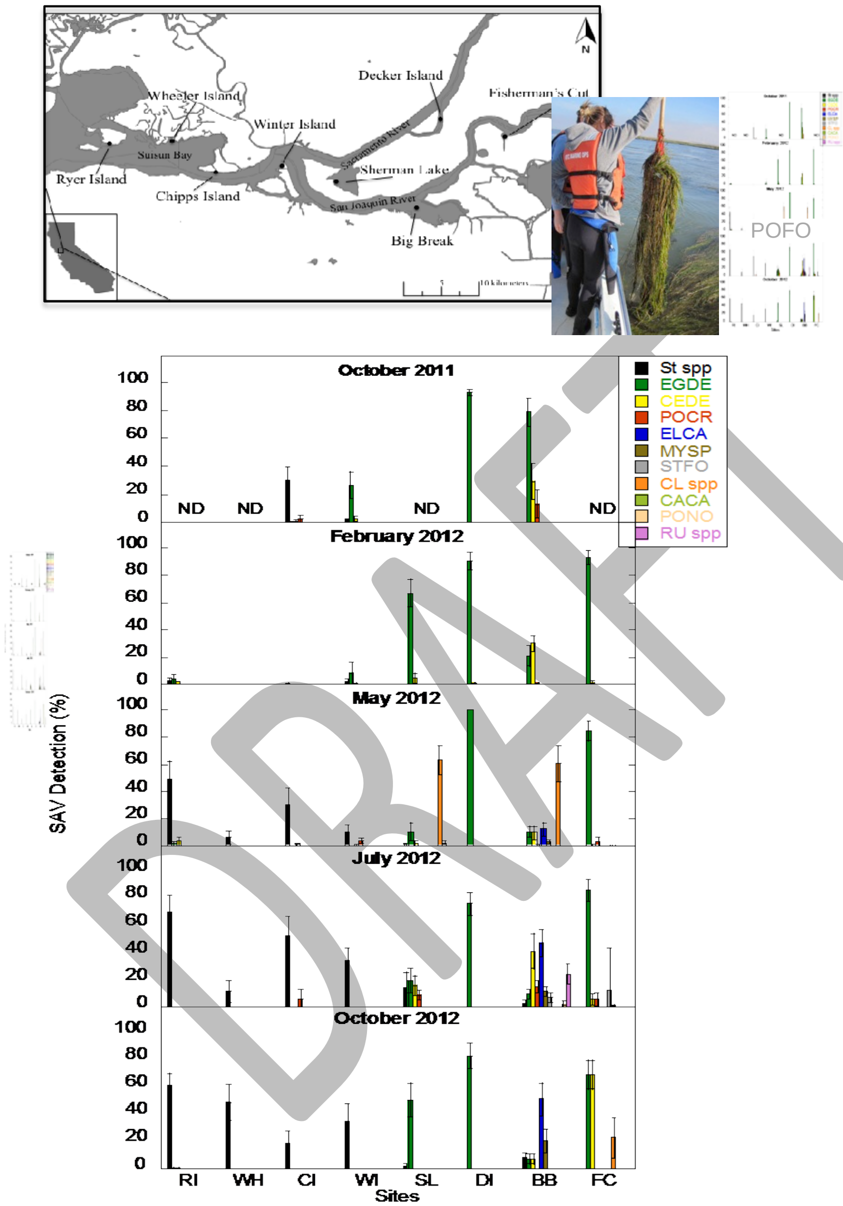

Figure 2.2. Relative abundance of submersed plant species in the west Delta and Suisun Bay (see map inset to interpret site abbreviations from west to east) in 2012 as estimated with a rake sampling method (Kenow et al. 2007). Species abbreviations as in Fig. 2.1, with the addition of the native Potamogeton foliosus *(POFO), the green alga* Cladophora *spp. (CL), and* Ruppia *spp. (RU). (Figure from Boyer et al. 2013)*

Recently, another floating invader, *Ludwigia* spp. (water primrose), has become very common in the Delta as well. As of 2014, it covered about the same acreage as *E. crassipes* (800 hectares; Khanna and Ustin, unpublished data). Rooted at the shoreline, this combination of *L. hexapetala*, *L. peploides*, and perhaps *L. grandiflora* (Khanna and Ustin, unpublished data), has now become a subject of concern, although there is not yet a program to control the plants.

The floating native species, *Hydrocotyle umbellata* (pennywort), was common during recent years and nearly as abundant as *E. crassipes*. Currently, it is much less abundant than both *E. crassipes* and *Ludwigia* spp. (Khanna and Ustin, unpublished data).

These six species, the submersed *Egeria densa*, *Ceratophyllum demersum* and *Stuckenia pectinata* and the floating *Eichhornia crassipes*, *Ludwigia* spp. and *Hydrocotyle umbellata*, will be the primary subjects of this review (Fig. 2.3), with a special focus on the invaders. A botanical description of each of these species is given below (from the Jepson Manual and Flora of North America, plus unpublished genetic work on *Stuckenia pectinata* from San Francisco State graduate student Melissa Patten).

Egeria densa (Brazilian waterweed) is native to warm temperate South America in southeastern Brazil, Argentina, and Uruguay. It grows with trailing stems up to 5 m long, producing roots at intervals along the stem. Although it is typically rooted in the sediment, it can also form mats of detached fragments. The leaves are produced in whorls of four to eight, 1–4 cm long and 2–5 mm broad, with an acute apex. It is dioecious, with staminate and pistillate (sometimes referred to as "male" or female", respectively) flowers on separate plants; however, all plants outside the native range, including California, are believed to be "male", with reproduction accomplished only through fragmentation. The flowers are 12–20 mm diameter, with three broad, rounded, white petals, 8–10 mm long.

Ceratophyllum demersum (coontail) is a submersed, native perennial that grows in still or very slow-moving water. The stems reach lengths of 1–3 m, with numerous side shoots making a single specimen appear as a large, bushy mass. The leaves are produced in whorls of six to twelve, each leaf 8–40 mm long, simple, or forked into two to eight thread-like segments edged with spiny teeth; they are stiff and brittle. The flowers are small, 2 mm long, with eight or more greenish-brown petals; they are produced in the leaf axils. The fruit is a small nut 4–5 mm long, usually with three spines, two basal and one apical, 1–12 mm long. *C. demersum* is not rooted; it can be found free-floating beneath the water surface, often among other plant species.

Stuckenia pectinata (sago pondweed) is a monocot, perennial rhizomatous herb native to California, with long stems (2-4 m in summer) and a submersed canopy of thin leaves near the water surface. *S. pectinata* was historically an important food for Canvasback ducks in ponds within Suisun Marsh (Jepson 1905) but was not recorded in the open waters of the San Francisco Estuary until very recently (Boyer et al. 2012, 2015). Morphology of these plants is quite variable, and a form outwardly resembling *Stuckenia filiformis* is common, with little to no secondary branching, leaves frequently > 1.5 mm and often 2-3 mm or more wide (with extremes to 3.7 mm), olive in color and blunt-tipped (fruits are seldom found but should be 2-3 mm in size with style and stigma reduced to a broad flattened disk at the top of fruit).

Figure 2.3. Species central to this review. Left, submersed species: Egeria densa *(top; photo Katharyn Boyer),* Ceratophyllum demersum *(middle, photo Ron Vanderhoff), and* Stuckenia pectinata *(bottom; photo Katharyn Boyer). Right, floating species*: Eichhornia crassipes *(top; photo Bob Case),* Ludwigia *spp. (center)*, Hydrocotyle umbellata *(bottom)*

In contrast, a form more closely resembling keys for *Stuckenia pectinata* is also present, and has a forking "zig-zag" (wide branch angle) pattern of branching, multiple orders of very leafy branches, with leaves 1 mm wide or less and seldom exceeding 1.5 mm, brighter green in color with more acutely-pointed leaf tips (fruits are seldom found but should be 2.5-5 mm with pronounced beaks resulting from persistent styles). Many specimens observed to date do not precisely match keys for either species, and the few fruits available have been intermediate between the two species (large but not beaked) (Boyer et al. 2015); however, recent genetic data (using the CO1 region of the mitochondrial DNA) indicate that samples representing a wide range of morphologies are all *Stuckenia pectinata* (Patten and Boyer, unpublished data). Additional analyses underway using microsatellite data will help to reveal whether there are fine-scale genetic differences across the region within this species that could lead to different observed morphologies, while common garden experiments are examining the degree of phenotypic plasticity that results from variation in flow velocities (Patten and Boyer, unpublished data).

Eichhornia crassipes (water hyacinth) is a free-floating perennial aquatic plant native to tropical and sub-tropical South America. With broad, thick, glossy, ovate leaves, water hyacinth may rise above the surface of the water as much as 1 meter in height. The leaves are 10–20 cm across, and float above the water surface on long, spongy and bulbous stalks. The feathery, freely hanging roots are purple-black. An erect stalk supports a single spike of 8-15 conspicuously attractive flowers, mostly lavender to pink in color with six petals. When not in bloom, water hyacinth may be mistaken for the smaller South American sponge plant (*Limnobium laevigatum*), recently discovered in the Delta (Anderson 2011). One of the fastest growing plants known (a mat of 10 plants can produce 650,000 in one growing season; Penfound and Earle 1948), water hyacinth reproduces primarily by way of runners or stolons, which eventually form daughter plants. Although each plant can produce thousands of seeds each year, these have a low germination rate outside their native range and seedlings grow slowly, taking a full growing season to produce flowers. The stembase can lie under water during winter and initiate rapid growth in the new growing season (Madsen, pers. comm.).

***Ludwigia* spp.** (water primrose) is well known as a noxious weed that invades and clogs waterways. It is perennial herb that grows in moist to flooded areas. The stem can creep over 2 meters long, sometimes branching. It spreads to form mats on the mud, or floats ascending in the water. The leaves are several centimeters long and are borne in alternately arranged clusters along the stem. The flower has 5 to 6 lance-shaped sepals beneath a corolla of 5 or 6 bright yellow petals up to 2.4 centimeters long. The fruit is a hard, cylindrical capsule. In the Delta, *Ludwigia peploides* and *L. hexapetala* are the primary species, but *L. grandiflora* may also be present (Khanna, pers. comm.).

Hydrocotyle umbellata (pennywort) is a perennial herb that is native to California and is also found elsewhere in North America and beyond. It can also be found growing as an introduced species and sometimes a noxious weed on other continents. It can be found creeping or floating with round leaves generally 1–5 cm wide. Its inflorescences are open umbels with up to 60 individual flowers on them.

2.3 Habitat Types in Which They are Characteristically Found

Egeria densa is found throughout the Delta in areas of moderate and low flow, along the margins of larger sloughs and in more protected areas such as smaller sloughs and breached islands (e.g., Sherman Lake, Franks Tract: Fig. 2.4). It can be found as far west as the confluence of the Sacramento and San Joaquin Rivers around Winter Island (Boyer et al. 2013). It grows densely throughout the water column in waters up to 7 m deep (Parsons and Cuthbertson 1992), but grows nearer to the surface in turbid waters (Bossard et al. 2000; Khanna, pers. comm.). Typically, it is rooted in the substratum throughout its distribution but it can also be found as a free-floating mat (Bossard et al. 2000).

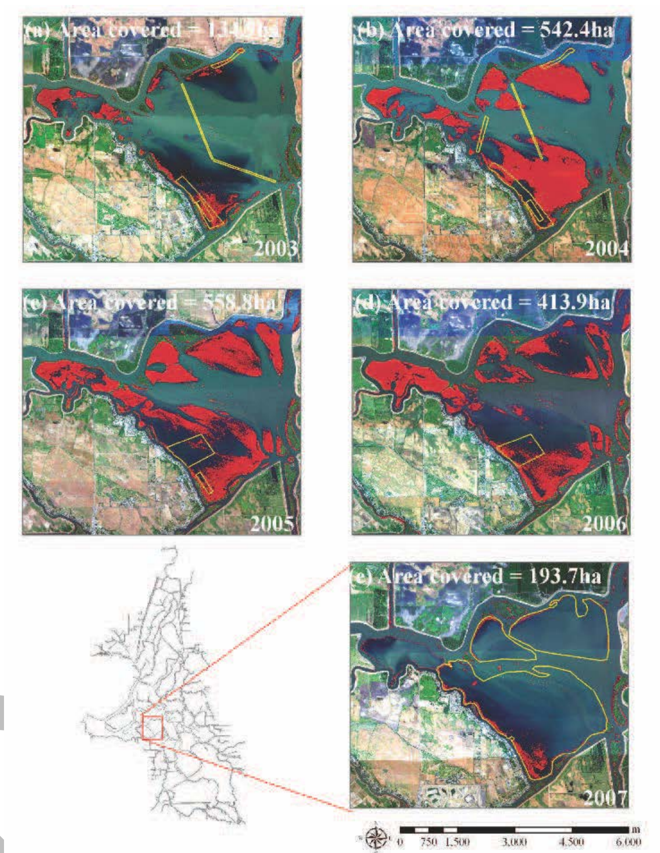

Figure 2.4. Submersed vegetation (primarily E. densa) coverage of up to 560 hectares within Franks Tract in the central Delta, 2003-2007 (figure from Santos et al. 2009)

Ceratophyllum demersum has been documented as abundant in the west and central Delta in areas of low flow (Santos et al. 2011; Boyer et al. 2013). This species was found with roughly half the frequency of *Egeria densa* within the central Delta region in one study (Santos et al. 2011). It is free-floating and may benefit from water column stability through co-occurrence with other submerged vegetation; in one survey, it more often occurred along with other species such as *E. densa* than on its own (Santos et al. 2011).

Stuckenia pectinata is less commonly found in the Delta than the other species described above, but still more common than all other native species besides *Ceratophyllum demersum*. It was found at about 25% of the frequency of *C. demersum* in a survey of the central Delta (Santos et al. 2011). With high salinity tolerance (maintaining its biomass even at a salinity of 15; Borgnis and Boyer, in revision), it forms large beds in the west Delta (e.g., Sherman Lake) and along shoals and island shores throughout much of the open Suisun Bay, as well as in sloughs interior to islands and the Suisun Marsh (Fig. 2.5; Boyer et al. 2015).

Eichhornia crassipes is found throughout the Delta in calm waters, but can be dislodged by boating

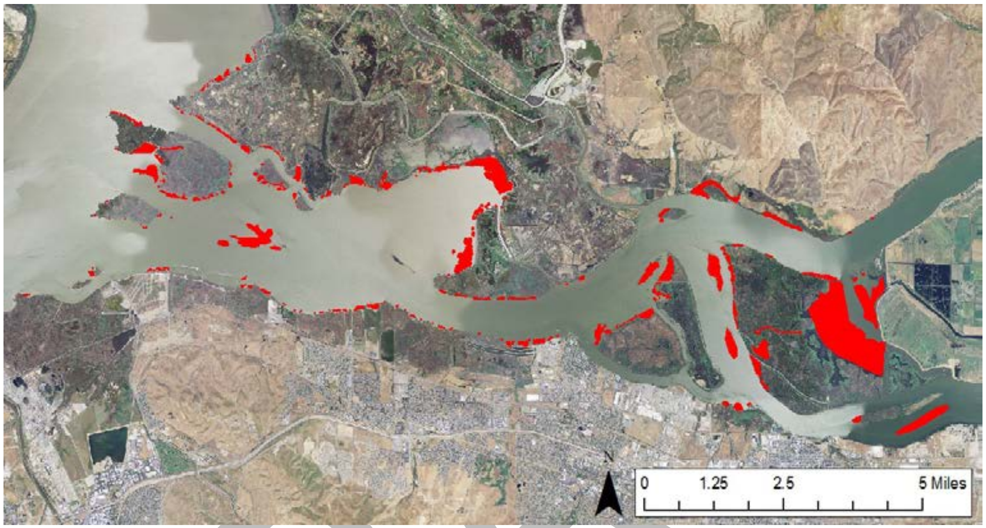

Figure 2.5. Spatial distribution of Stuckenia sp. from Ryer Island in Suisun Bay to Sherman Lake in the west Delta, as determined from digitizing and ground truthing aerial imagery (Google Earth), 2012. Coverage is estimated to be ~500 hectares in this region. Image unpublished, based on data in Boyer et al. 2015.

activity, high tides, or wind, and can be seen rafting through open waters with its stout leaves acting as sails (Boyer, pers. obs.). It has been extremely abundant near the city of Stockton in the last several years (see Literature Cited, Local and Regional Press Reports, for many news articles). It has also been very abundant near the Tracy Fish Collection Facility and River's End Marina on Old River (see Literature Cited). It is typically found along channel edges with more stable flow conditions, thus minimizing wash out, or in narrow channels or low flow basins (e.g., marinas, breached island interiors, inside of tule islands) where there is protection from higher velocity flows. Water depth alone is not a limitation, as it does not root in the sediment.

***Ludwigia* spp.** is also found throughout the Delta in calm waters and can be found interspersed with *E. crassipes* and *Hydrocotyle umbellata*. It is typically found in shallow water where it is rooted in the sediment and has creeping stems that reach across the water surface. It often grows in matted stands, with thick white spongy roots at floating nodes. It frequently climbs over other plants.

Hydrocotyle umbellata is found in similar habitats to *Ludwigia* spp., attached to the sediments in shallow water and creeping across the water.

2.4 Spatial and Temporal Trends in their Distribution and Abundance

A regular, comprehensive mapping program for aquatic vegetation does not exist for the Delta region. Several grant-funded efforts to conduct remote sensing have provided valuable information, and have led to improvements in mapping techniques. In particular, recent work to incorporate hyperspectral imagery has aided in the distinction of some of the native submersed species (*Ceratophyllum demersum* and *Potamogeton nodosus*) from non-native ones (*Egeria densa*, *Myriophyllum spicatum, Potamogeton crispus*). However, distinction among the non-native species was not well achieved, especially in the western region of the Delta where green algae obscured the spectral signal of *Egeria densa* and *Myriophyllum spicatum* was confused with *E. densa* (Santos et al. 2012). Further, although the native *Stuckenia* sp. (presumed to be *S. pectinata* based on recent genetic work; Patten and Boyer unpublished) had a distinct spectral signature in greenhouse tanks, patches were too small to be detected by remote sensing in the area of the Delta studied (Santos et al. 2012). Mixed species stands are also problematic for remotely determining species presence and extent as described above. Hence, on the ground monitoring of relative abundance, biomass, and preferably, primary production (through multiple biomass estimates over time to estimate turnover) is necessary to complement the remote sensing work.

Below, we summarize what is known of the spatial and temporal extent of each of the six species emphasized in this review, primarily resulting from individual grant-funded efforts that provided a window into the distribution over, at most, a few years at a time.

Egeria densa is thought to have been introduced to the Delta in 1946 (Light et al. 2005) through aquarium dumping and has spread throughout the region (Anderson 1990; Foschi et al. 2004; Santos et al. 2009). It was discussed without signs of alarm in a CA Department of Water Resources report that described water quality conditions over a 30-year period (DWR 1993); however, by 1996, Grimaldo and Hymanson (1999) described thick stands harboring many non-native centrarchid fish. It may have replaced native submersed aquatic plants in much of this area (Lund et al. 2007). In terms of interanual trends, there has been a major expansion in acreage over the last several years. In 2007, submersed vegetation dominated by *E. densa* covered ~2000 hectares (~8%) of Delta waters (Santos et al. 2009) and this number increased to ~2900 hectares (~11%) according to remote sensing and ground-truthing in 2014 (Khanna and Ustin, unpublished data). Application of herbicide (by the California Department of Boating and Waterways, now the CA Department of Parks and Recreation Division of Boating and Waterways, DBW) in areas such as Franks Tract has the potential to reduce acreages locally, especially if conducted in spring (Santos et al. 2009; see Fig. 2.4, acreage was reduced by >50% after fluridone application in April 2007, as opposed to after July 1 in the other years). However, a very small proportion of the Delta is included in the management program, with the most area treated in any year covering only 4-5% of the Delta waterways (DBW 2005). During periods of drought, this species shifts further east into the Delta (Boyer, pers. obs.), as its survivorship is very low at salinities of 5 and above (Borgnis and Boyer, in revision; see Chapter 4). In terms of seasonal trends, one study documented a greater acreage and percent cover in the central Delta in fall (October 2007) than in the summer (June 2008) (Santos et al. 2011, see Fig. 2.1). Though its biomass declines in winter, it maintains aboveground shoots (Pennington and Systma 2009; Santos et al. 2011; Boyer et al. 2013, see Fig. 2.2).

Ceratophyllum demersum was documented to change in abundance seasonally, with greater acreage and percent cover in October 2007 (284 ha, 44% cover of the waterways sampled) than in June 2008 (59 hectares, 9%) within the same central Delta region (Fig. 2.1, Santos et al. 2011). A similar pattern was found at Fisherman's Cut, with rake detections at 70% in October 2012, but little to no presence in February, May, and July 2012 (Fig. 2.2, Boyer et al. 2013). However, its frequency of occurrence at Big Break varied considerably seasonally, with 40, 10, 30, and 5% detection over the four sampling periods in 2012, respectively. In the same study there were no detection at Decker Island, and less than 10% detection at Sherman Lake in any season (Fig. 2.2, Boyer et al. 2013). We found no records of *C. demersum* variation in abundance in the Delta over longer periods of time.

Stuckenia pectinata appears to have increased in acreage over the last several decades (Fig. 2.6, from Boyer et al. 2015). Comparing digitized imagery over time for Suisun Bay, and in doing so assuming that historical stands were essentially monotypic as they are at present, there was little change in acreage between 1993 and 2002. However, there was about a 30% increase in acreage (43 hectares) in the Suisun Bay region between 2002 and 2012, with many new, mostly small beds occurring along nearly every stretch of shoreline and large increases in acreage in the cove on the southwest side of Ryer Island and along the south sides of Simmons and Chipps Islands. In the west Delta, a similar increase in acreage (37 hectares) appears to have occurred over the decade ending in 2012, a 13% increase since 2002; however, this increase is less certain due to the many species present within Sherman Lake that make accurate estimates much more difficult. Still, there appeared to have been large gains in *S. pectinata* acreage in Sherman Lake, offshore and to the west of Sherman Island, and to the west of Winter and Browns Islands (Fig. 2.7). In a 2014 remote sensing survey followed by groundtruthing of point locations, *S. pectinata* was found in 26% of sampled points in the Delta (Khanna and Ustin, unpublished data). In that survey it was found to have an average relative cover of 50%, but 100% in open water areas of the Delta, perhaps suggesting a distinct environmental niche (Khanna and Ustin, unpbublished data; Khanna, pers. comm.). It is not clear why *Stuckenia pectinata* acreage would be expanding over the last 20 years, although increased water clarity and thus greater light availability may be partially responsible (Wright and Schoellhamer 2004; Schoellhamer 2011; Hestir et al. 2013; see Chapter 4).

Eichhornia crassipes was introduced to the Sacramento River in 1904 by horticulturalists (Finlayson 1983; Cohen and Carlton 1998; Toft et al. 2003) or perhaps through garden escape (Light et al. 2005). It was estimated to cover 160-300 hectares of the Delta (~1% of the water area) during the period of 2004-2008 (Santos et al. 2009); however, this species has expanded in coverage, with ~800 hectares in 2014, or about 3% of the water area (Khanna and Ustin, unpublished data). This increase in cover may be partly attributable to a delay in chemical treatment over two years (2011 and 2012) owing to permitting issues (Llaban, pers. comm.); however, in general, these control methods seem to have little impact on year-to-year coverage of water hyacinth (Khanna pers. comm., unpublished data). There also seem to have been favorable conditions during the years of rapid increase in cover, including but not limited to a low occurrence of frost in winter (Khanna, pers. comm.). Positions of colonies can shift within a season and from year to year due to drifting and movement on the tides and with wind or other disturbance (Santos et al. 2009).

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***Ludwigia* spp.** has expanded greatly in coverage between remote sensing surveys conducted in 2008 and 2014 (Khanna and Ustin, unpublished data). It had low coverage during the period of 2004 to 2008, but is now equal in coverage to *E. crassipes*, with ~800 hectares present in 2014 (Khanna and Ustin, unpublished data).

Hydrocotyle umbellata has declined in coverage between the remote sensing surveys conducted in 2008 and 2014 (Khanna and Ustin, unpublished data). Between 2004 and 2008, *H. umbellata* was comparable in coverage to *E. crassipes*. Considering the large increases in *Ludwigia* spp. seen in 2014, it is possible that *Ludwigia* has a competitive advantage over *H. umbellata* under current conditions.

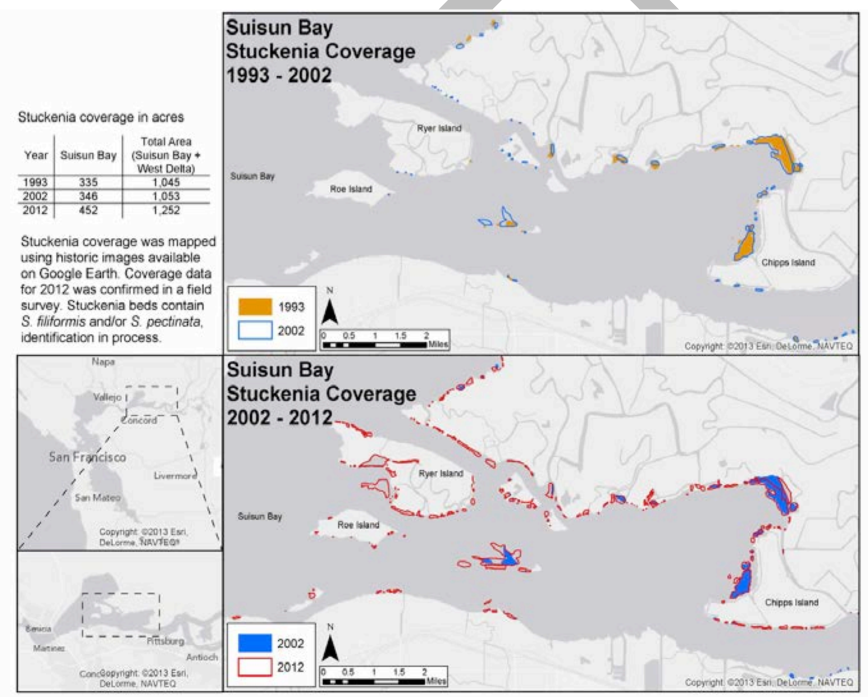

Figure 2.6. Decadal changes in coverage of Stuckenia sp. within Suisun Bay, as mapped using digitized and ground-truthed Google Earth images. From Boyer et al. 2015

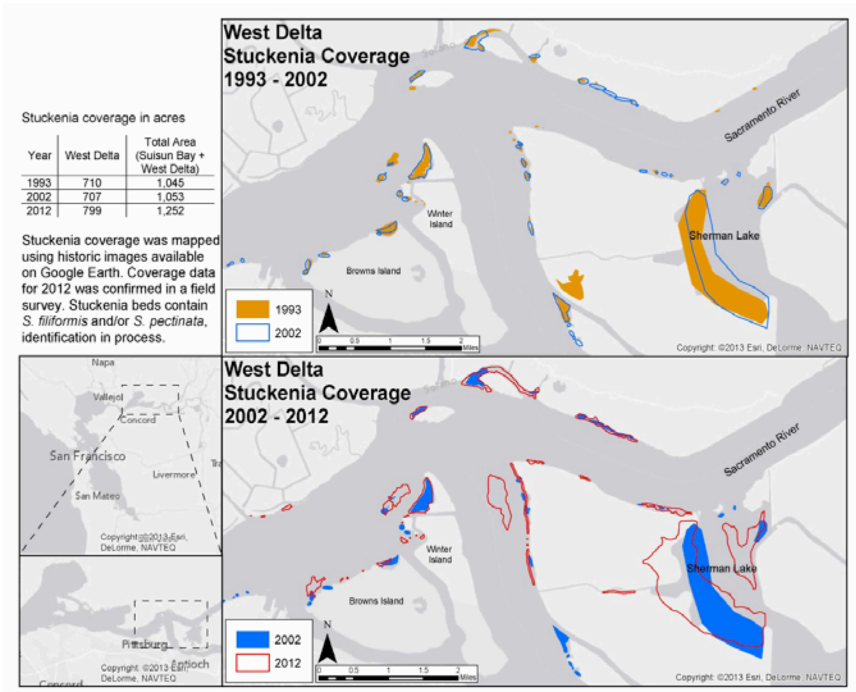

Figure 2.7. Decadal changes in coverage of Stuckenia sp. within the western portion of the Delta, as mapped using digitized and ground-truthed Google Earth images. From Boyer et al. 2015

3. Role of Submersed and Floating Aquatic Vegetation in Supporting Delta Ecosystem Services

Submersed and floating aquatic vegetation are natural components of estuaries, providing benefits in the form of carbon storage, uptake of nutrients, oxygenation of waters, trophic support through direct consumption by grazers or contributions to the detrital food web, provision of surfaces for algal and invertebrate attachment (also providing trophic support), and predation refuge for small fish. Negative effects tend to emerge in the case of non-native species that have invaded large areas and that have characteristics unlike those of the native species (especially when the invaders are at high densities), thus leading to undesirable changes in a number of factors, including nutrient dynamics and food web support. Here we review both the positive and negative effects of submersed and floating vegetation, based on the published literature from other regions as well as local studies where available.

3.1 Conceptual View of Positive and Negative Effects of Submersed and Floating Aquatic Vegetation on Ecosystem Services.

Anderson (2008) proposed a draft conceptual model of the effects of submersed, floating, and emergent vegetation on water quality and fish habitat in the Delta (Fig. 3.1). In general, low to moderate densities or open growth forms of any species may have beneficial functions, including provision of habitat and food web support, but the dense stands typical of the worst invaders tend to produce negative effects. For example, dense canopies of the floating *Eichhornia crassipes* may shade phytoplankton and exclude submersed native plants such as *Stuckenia*. Dense stands of submersed plants (primarily *Egeria densa*) can draw down oxygen at night, increase water temperatures by increasing water residence time, increase pH to the benefit of plants that can utilize bicarbonate as a carbon source (e.g., *E. densa*, see Section 4.1.4), and harbor large non-native fish in the shadows of the canopy, which could possibly lead to predation on smaller adult and juvenile native fish. In contrast, the open water beneath naturally sparse canopies of native submersed species such as *Stuckenia pectinata* may provide a more stable dissolved oxygen setting, accessible invertebrate food resources, and a paucity of large predator hiding places – in all, it has the potential to provide more suitable habitat for native fish species than dense *E. densa* beds (Fig. 3.1). As expected in a conceptual modeling exercise, there is not necessarily data to support all of the effects and feedbacks (e.g., there is no detailed dataset for the composition or abundance of fish species that utilize *Stuckenia* beds); in these cases, the model can be used to identify hypotheses that should be tested with further data collection and experimentation.

Below, we detail a number of adverse effects that may result from introduced macrophyte species when they become dense and widespread in invaded regions. Potential adverse effects include changes to water quality, a decline in phytoplankton and native plants, a change in the physical structure of the habitat, alterations of trophic interactions, impediments to navigation and industry, and visual impacts.

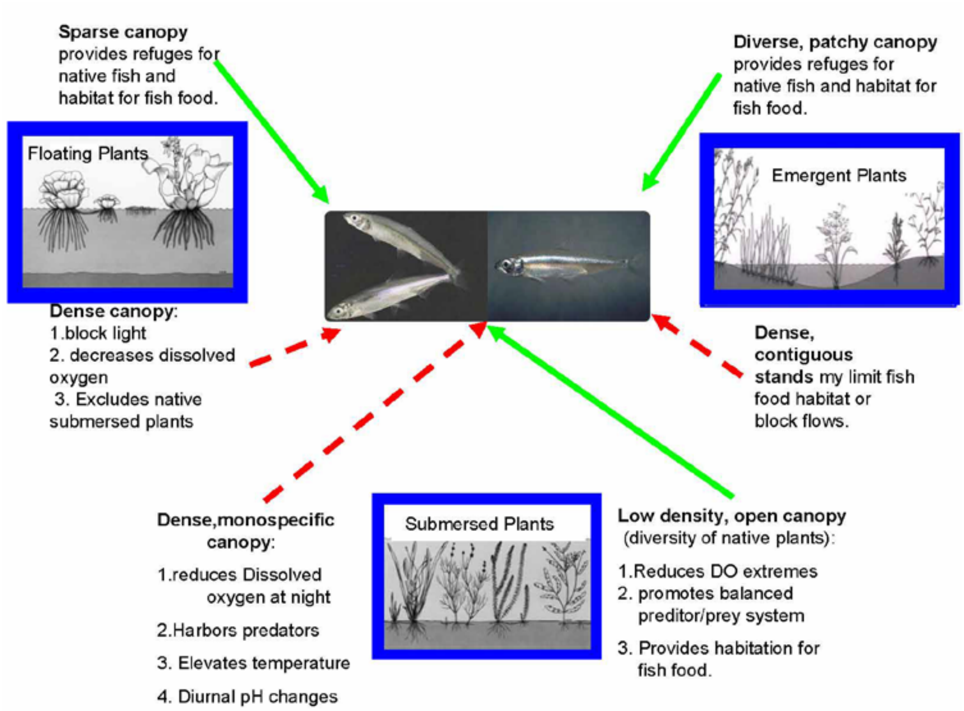

Figure 3.1. Conceptual model of the effects of Delta macrophyte canopy structure on provision of fish habitat. Arrows show direction and primary effect caused by interaction of each "ecological type" of aquatic plant on fish (red, dashed = negative effect, green, solid = positive effect. From Anderson 2008

3.1.1 Changes to Water Chemistry

Dissolved oxygen

Submersed species such as *E. densa* have the potential to greatly draw down dissolved oxygen levels within thick mats (e.g., Getsinger 1982). Dissolved oxygen in plant beds declines at night due to a lack of photosynthetic oxygen production to counter oxygen needs for respiration, and these diurnal swings can be especially pronounced in high density submersed macrophyte beds (Fig. 3.1). Interestingly, *E. densa* was promoted as a way to oxygenate waters for fish during its early introduction period (Cook and Urmi-Konig 1984).

Dense mats of *E. crassipes* can lead to large reductions in dissolved oxygen through drawdown at night as well as prevention of gas exchange at the water's surface (Madsen 1997; Hunt and Christiansen 2000; Perna and Burrows 2005) and through shading photosynthetic species in the water including phytoplankton and submersed vascular plants (Malik 2007). In the Delta, drawdown of dissolved oxygen has been documented in areas of rapid *E. crassipes* growth, even in places with significant tidal exchange (Dow Wetland, directly off the mainstem of the San Joaquin River, with 1-2 m tidal variation; Greenfield et al. 2007). Further, decomposition of *E. crassipes* following mechanical treatment can lead to high biological oxygen demand and drawdown of oxygen in areas with low flow, creating unfavorable conditions for fish and invertebrates and even fish kills (dissolved oxygen concentration <2.3 mg l^{-1}; US EPA 1986). For example, Greenfield et al. (2007) found dead bluegill sunfish and carp during weeks of anoxic waters after an experimental *E. crassipes* shredding operation at the low-flow Lambert Slough. With this in mind, the CA Parks Division of Boating and Waterways must monitor dissolved oxygen levels during weed control, maintaining a minimum of 5-7 mg l^{-1}, as mandated by the Central Calley Water Quality Control Board (Moran, pers. comm.).

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Notably, decreased oxygen in the sediments can increase mobility of phosphorus, contributing to nutrient loading (Scheffer and Van Ness 2007). In support of this concept, Cornwell found high phosphorus release in soils of submersed macrophyte beds in the Delta; if conditions conducive to phosphorus release develop over time in these beds, they could promote a positive feedback in which phosphorus is supplied to the plants, especially through porewater uptake (Cornwell et al. 2014; J. Cornwell, pers. comm.).

pH

High abundance of submersed macrophytes can lead to increased pH as CO_2 is drawn down during photosynthesis, leading to diurnal swings in pH and to bicarbonate (HCO_3^-) becoming the primary form of dissolved inorganic carbon (DIC) available (Sand-Jensen 1989; Santamaria 2002). This can work to the advantage of species that can use bicarbonate efficiently as their carbon source (e.g., *Egeria*, Cavalli et al. 2012). We are not aware of data on pH within submersed macrophyte beds in the Delta to date, but expect both the changes in pH and these effects on the form of available DIC would be greatest in thick *E. densa* beds and in places with limited water flow.

Nutrients

Both *Egeria densa* and *Eichhornia crassipes* are known for their abilities to take up nutrients and store them for later use (e.g., Gopal 1987; Reddy et al. 1987). *E. crassipes* has been used in a number of regions as a tool to remove nutrients from the water column, both in pilot and demonstration scale projects and in full scale wastewater treatment (reviewed by Malik 2007). Despite this propensity for nutrient uptake, Delta-wide effects of these species on water column nutrient removal could be relatively low considering only about 3% of Delta waters contain *E. crassipes* and 11% contain *E. densa* as of 2014 (Khanna and Ustin, unpublished data). To understand the contribution of these species to nutrient cycling, including in comparison to other producer groups (e.g., ~9500 hectares or 37% of Delta waters contained emergent plant species in 2014; Khanna and Ustin, unpublished), data on productivity rates, sequestration of nutrients within perennial tissues, and recycling within tissues and from the water column and sediments would be needed. One Florida study comparing nutrient removal effects over a range of macrophyte species found *E. crassipes* to rank much higher than many others (including *Hydrocotlye umbellata* and *Egeria densa*) in N removal during summer (Reddy and DeBusk 1985). P removal was also higher in *E. crassipes* than in all other species in summer. Interestingly, in winter, *H.*

umbellata was higher in both N and P removal rates than all the other species (Reddy and de Busk 1985).

In areas of densely growing macrophytes, intraspecific competition can lead to continuous shedding of dead tissues that decompose in place and may serve as a source of remineralized nutrients to the existing plant bed as well as other producers (Carignan and Neiff 1992; Rommens et al. 2003). Seasonal senescence of *Eichhornia crassipes* is generally slow and occurs during fall and winter (Carignan and Neiff 1992; Pinto-Coelho and Greco 1999; Battle and Mihuc 2000; Spencer 2005). *Egeria densa* sheds tissues in winter even though it does not fully senesce within the Delta region (Fig. 2.2, Boyer et al. 2013; Santos et al. 2011). In both cases, natural senescence is likely to result in a slow release of dissolved organic compounds from plants in the water column that may be utilized by the macrophytes or other producers locally, or transported away with water flow. Accumulation of dead organic matter within sediments of the beds appears limited in open water areas; sediment flux measures by Cornwell et al. (2014) in Sherman Lake, Big Break, and Franks Tract (all sites with substantial *E. densa* populations) did not suggest high rates of sediment respiration or nitrogen release, although rates tended to be higher than in non-vegetated areas measured in Suisun Bay. However, rapid deposition of dead macrophyte tissue in low flow areas may be a significant source of nutrients fueling macrophyte growth. For example, control methods that leave large quantities of shredded water hyacinth material in place can lead to increased water column nutrients, especially total P (up to 5-fold increases) and organic P (up to 2-fold increases) and to a lesser extent, total N (3-fold increase at one site) (Greenfield et al. 2007). This elevated nutrient effect was found to be short-lived (<4 days) where there was tidal exchange but water column nutrients were elevated at least several weeks after treatment in a quiescent site (Greenfield et al. 2007) where a related study documented significant quanities of the shredded debris even after six months (Spencer et al. 2006). These studies highlight that water residence time and flow rates at any one location will critically affect the degree to which macrophyte biomass accumulates and releases nutrients within the beds, whether as a result of control efforts or other abrupt changes in conditions (e.g., extended periods of frost for *E. crassipes*, or increased salinity for *E. crassipes* or *E. densa*; see Chapter 4) that cause rapid plant mortality.

3.1.2 Changes to physical properties of water

<u>Flow</u>

In general, dense submersed vegetation has the potential to slow the velocity of water, thereby initiating a positive feedback loop in which the favorable lower flows permit greater growth and spread (e.g., *E. densa*, Roberts et al. 1999). The density of the vegetation throughout the water column influences the degree to which water flow is affected (>40% reduction in dense *E. densa* beds; Wilcock et al. 1999) and varies with both plant morphology and density. Submersed plants may also facilitate the establishment and spread of floating plants through reduction in flow, permitting floating plants to better remain in place and spread locally (see Khanna et al. 2012, and Chapter 4). Dense floating macrophytes also can reduce flow under already moderately low flow conditions (Penfound and Earle 1948).

Light

Dense floating and submersed vegetation greatly reduce light penetration through the water column, shading other plants beneath. However, *E. densa* is also capable of reducing suspended sediment, creating clearer water in the vicinity of the plants (Tanner et al. 1993; Hestir et al. 2013). Grimaldo and Hymanson (1999) found secchi depth increased to 2 m in patches of *E. densa* in Franks Tract (central Delta), up from 0.5-1 m outside of patches.

Temperature

E. crassipes infestations lead to increased water surface temperatures through reduction in water flow (Penfield and Earle 1948). *E. densa*, too, causes increased water temperatures during the day, which helps to reduce heat loss at night (Grimaldo and Hymanson 1999).

3.1.3 Effects on algae and native macrophytes

A number of changes to the local environment by nuisance aquatic macrophytes could impact other species of primary producers, including native vascular plants and algae. First, shading of the water column by dense stands of floating or submersed macrophytes can reduce the light available to native submersed species, which tend to have more sparse growth forms and less potential to shade other species themselves (see Anderson 2008 conceptual model, Fig. 3.1). Shading of phytoplankton and benthic microalgae could also result from dense canopies or mats of aquatic macrophytes such as *Egeria densa* or *Eichhornia crassipes. E. densa* can reduce suspended sediment concentrations through baffling of particles out of suspension (Hestir et al. 2013); however, shading from thick mats could minimize any potential positive effects of sediment removal to other submersed primary producers. Second, thick mats of *E. densa* reduce water flow, and although floating vegetation is less likely to reduce water motion, a dense coverage over the water can reduce the generation of wind waves across the water surface. Third, reductions in dissolved oxygen within *E. densa* mats or beneath *E. crassipes* could also limit other producers among or below these plants. Fourth, a number of submersed and floating macrophytes, including *Eichhornia crassipes*, have been noted to have allelopathic effects on algae and microbes (Shanab et al. 2010). Removal of *E. crassipes* may lead to increases in *E. densa* abundance (Khanna et al. 2012), most likely due to increased light, but perhaps due to a combination of factors described above. Chapter 4 further describes the interactions between species that may influence abundance of introduced and native macrophyte species.

Submersed vegetation and the roots of floating vegetation provide surfaces for the growth of epiphytic algae and attachment points for filamentous algae where there is sufficient light (Fig. 3.2). These in turn affect the habitat and food availability to invertebrates and fish, and can influence nutrient cycling; e.g., filamentous algae attached to *Potamogeton crispus* was found to increase phosphorus retention of an experimental pondweed assemblage (Engelhardt and Richie 2002). These algae can also be considered

Figure 3.2. Green filamentous algal mats attached to Egeria densa *in Sherman Lake, May 2012. Photo, Katharyn Boyer*

nuisance species if they become overly abundant. Observations of thick green algal mats attached to *E. densa* have been made in a number of locations within the Delta (Santos et al. 2012; Boyer unpublished, Fig. 3.2; Llaban and DBW staff, pers. comm.).

3.1.4 Trophic support

Macrophyte invasion can lead to changes in structural complexity of the habitat, altering composition and abundance of invertebrates, which can have effects on higher trophic levels (e.g., Toft et al. 2003; Schultz and Dibble 2012). Direction and magnitude of change are difficult to predict in terms of desirable food for fish; however, thick stands of *Egeria densa* are thought to make access to invertebrate food resources difficult for fish, while locally clear water and dark, shadowy hiding places appear to increase predation risk compared to other habitats (Grimaldo and Hymanson 1999; Brown 2003; Nobriga and Feyrer 2007). The degree to which these modifications to food and predator conditions impact native fish in particular is unclear, nor have there been comparable studies in native SAV beds (e.g., *Stuckenia pectinata*) to support the assertion that the typically more open native plant canopies and greater turbidity (expected to be less reduced through baffling of sediment particles out of the water column) create more favorable habitat for native fish (Fig. 3.1). There is evidence that thick stands of *Egeria densa* impede the movement of small (including juvenile) fish, including natives such as salmonids, splittail, and Delta smelt (Brown 2003). It is possible that *E. densa* could be managed to maintain lower densities, and that this would permit increased access to food resources and reduce predation risk as the more open native plant canopies are hypothesized to do (Fig. 3.1).

Eichhornia crassipes may also modify the food resources available to higher trophic levels. Floating macrophyte invasion of open water can increase the surface area available for epiphytic invertebrate colonization (Brendonck et al. 2003). However, when native floating macrophytes are replaced, there can be a large change in species compostion of the invertebrate assemblage. For example, in the Delta, large differences in the epiphytic invertebrate assemblage were found on *E. crassipes* versus the native floating species, pennywort (*Hydrocotyle umbellata*) (Toft et al. 2003). Microcrustacean zooplankton can be more abundant with no vegetation than with *E. crassipes* present (Brendonck et al. 2003). A study in Uruguay found calanoid and cyclopoid copepods to be less abundant at sites with *E. crassipes* than with *Stuckenia pectinata* or no vegetation (Meerhoff et al. 2003). Still, the literature on *E. crassipes* effects on zooplankton are inconsistent, perhaps because there are many factors that might interact to affect zooplankton, including the effects of density of *E. crassipes* on predator abundance (Villamagna and Murphy 2010).

In terms of food web support for fish, consumption of *E. crassipes* appears to be minimal, as it is a nutritionally poor diet choice for herbivorous fish (Cowx 2003). For carnivorous fish, the presence of *E. crassipes* may change the invertebrate foods available relative to those on the native *Hydrocotyle umbellata* (Toft et al. 2003). Although both assemblages are dominated by amphipods, large drawdowns in dissolved oxygen (see Section 3.1.1) make *E. crassipes* a less favorable location for feeding due to physiological constraints on the fish (Simenstad et al. 1999). In fact, dissolved oxygen under dense or decomposing mats of *E. crassipes* can be dangerously low for fish (lower than 4.8 mg l^{-1}; reviewed by Villamagna and Murphy 2010). The abundance of *E. crassipes* is linked to the value of the habiat it creates for fish; at some (undefined, and probably site-specific) lower level of abundance, adequate light for phytoplankton production to support zooplankton, surfaces for algae and invertebrate attachment, and dissolved oxygen all support fish presence and diets, while at higher abundance these features are diminished or even threatening to fish (McVea and Boyd 1975; Brown and Maceina 2002).

Similarly, for birds, presence of *Egeria densa* or *Eichhornia crassipes* may benefit certain birds through provision of invertebrate or fish prey attracted to the physical structure; however, access to these prey becomes diminished when canopies become excessively dense (Brendonck et al. 2003), and declines in dissolved oxygen (see Chapter 3) that affect prey would also limit value to birds. Neither of these species is known to be a valuable food source for birds themselves although American coots are known to eat *E. crassipes* (Villamagna 2009). In contrast, *Stuckenia pectinata*, a native species subject to replacement by these two invaders, is a very nutritious food source that was heavily used by canvasback ducks historically (Jepson 1905).

3.1.5 Navigation and industry

Submersed and floating vegetation both have the capacity to clog navigation channels, marinas, intake pipes for potable water supply, industry, and agriculture. Highly productive aquatic plant beds can have devastating effects on local economies and quality of life for recreational users of waterways. Thick mats of *Egeria densa* hinder a wide variety of recreational and commercial activities, including boating, fishing, swimming and water pumping for potable supply and irrigation (Bossard et al. 2000). *Eichhornia crassipes* can grow so densely on the water's surface that it impedes navigation by recreational motorboats and ships, becomes entrained in water pumps, and chokes irrigation channels (Bossard et al. 2000; Toft et al. 2003). In turn, boating and shipping activities can facilitate spread of these invaders; *E. crassipes* can become dislodged from colonies and drift to other locations, and *E. densa* can be chopped into fragments that can become propagules for establishment elsewhere through water movement.

3.1.6 Aesthetics

Some invasive macrophytes are very attractive, but lose their aesthetic appeal when there is a loss of commercial, industrial, municipal, and recreational use. *Eicchornia crassipes*, in particular, has very showy and attractive purple flowers, a likely reason for its original introduction in many areas of the world.

4. Factors Contributing to the Prevalence of Submersed and Floating Aquatic Vegetation in the Delta

4.1 Conceptual Models of Growth, Propagation and Environmental Characteristics that Enhance or Limit Growth

There are a number of factors known to influence aquatic vegetation in low salinity and fresh regions of an estuary. Anderson (2008) developed a draft conceptual model to describe the ways in which submersed, floating, and emergent species are likely to respond to and modify conditions within the Delta. This effort included a general model for establishment, growth, and dispersal, reprinted here as Fig. 4.1. To briefly review this model, both submersed and floating macrophytes are influenced by light levels, with submersed plants adapted to lower light conditions. Carbon dioxide limits photosynthesis especially for submersed plants in thick stands where drawdown and high pH reduce availability, but many submersed species are capable of substituting bicarbonate as a source of inorganic carbon. Water quality conditions, including nutrient levels, are known to strongly influence growth of these species. Sediment characteristics, including nutrients and grain size distribution affect growth and anchoring of submersed vegetation. Local flow conditions help to maintain floating plants in place and help submersed species to accumulate large quantities of biomass.

Anderson (2008) described "sub models" for submersed and floating species which further detailed important determinants of establishment, growth, and dispersal for each vegetation type. These are reprinted here as Fig. 4.2A and B. Below we review these sub models in detail and the literature supporting each of them.

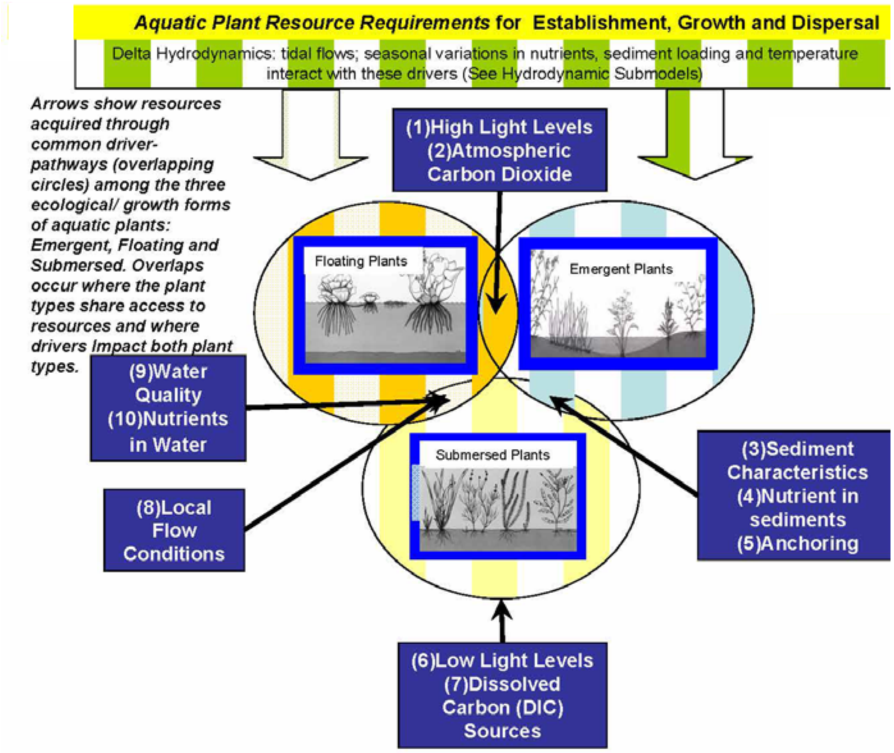

Figure 4.1 Aquatic plant resource requirements for establishment, growth and dispersal, as described in a draft conceptual model by Anderson (2008)

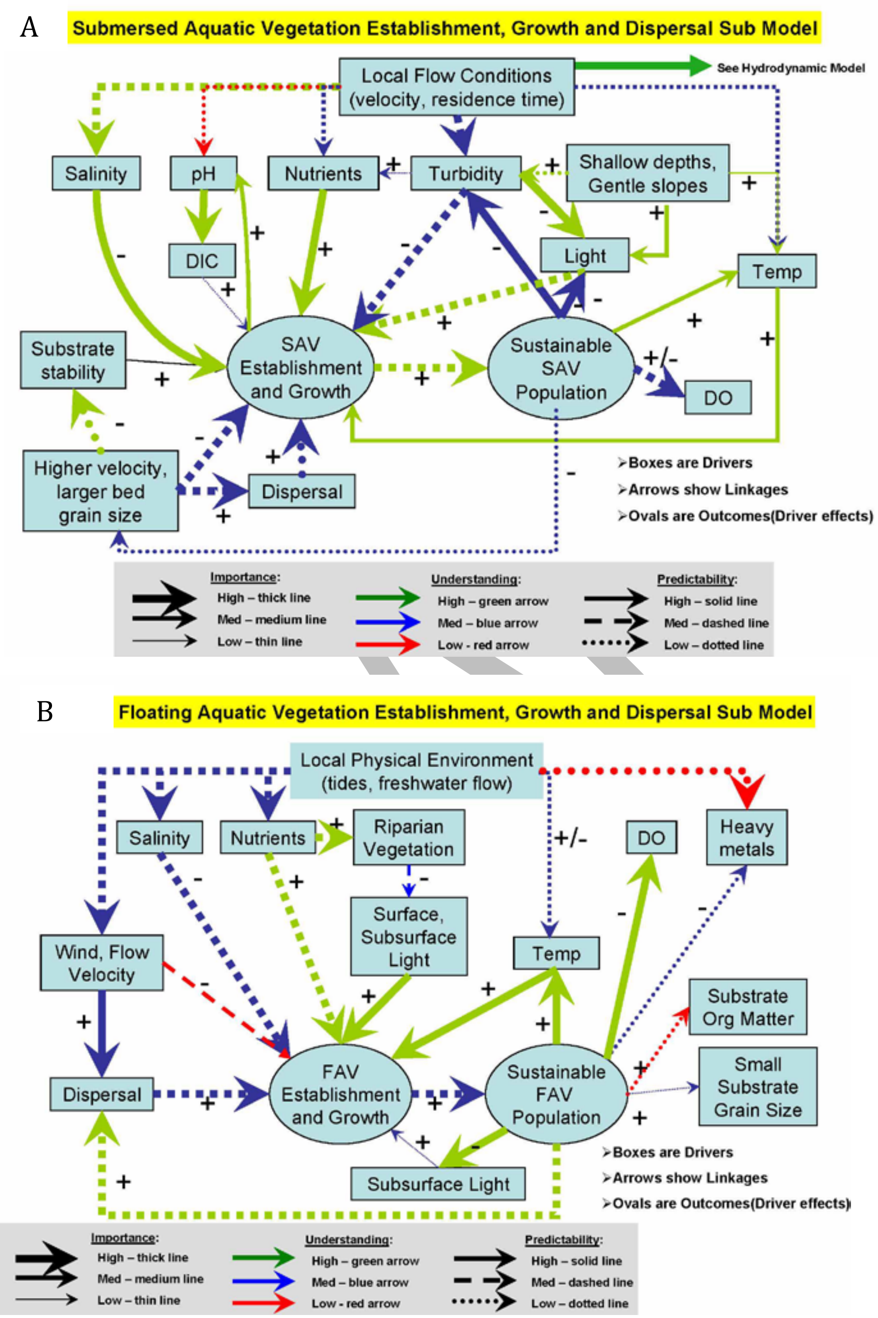

Figure 4.2. Sub models describing important drivers of establishment, growth, and dispersal in submersed (A) and floating (B) aquatic vegetation. From draft conceptual model by Anderson (2008)

4.1.1 Light

Light is essential to photosynthesis in all plants and is generally adequate for floating species such as *Eichhornia crassipes*, although periods of reduced light due to extended cloud cover (during El Niño years) have been implicated in a major decline in this species' vigor and cover in Lake Victoria in Africa (Williams et al. 2005, 2007). Floating species can benefit by shading submerged plants (see Section 4.1.7 below), which frees other resources such as nutrients and favors development of sustainable floating macrophyte populations (Fig. 4.2B).

Submersed species must cope with lower light conditions than floating species due to attenuation of photosynthetically-active radiation (wavelengths of 400-700 nm, PAR) through water. PAR is further attenuated by particles in the water, including sediments and phytoplankton. Light availability is very important to establishment of submersed species at the sediment surface (Fig. 4.2A), whether from seeds, turions, or vegetative fragments, depending on the species. After establishment, dense plant growth can lead to self-shading of tissues lower in the water column. However, *E. densa* reduces turbidity of the water, leading to greater light penetration (Fig. 4.2A; Hestir et al. 2013), which is likely to represent a positive feedback toward greater growth even at depth. *Stuckenia pectinata* has its canopy of leaves within the upper portion of the water column, which provides access to higher light levels near the surface, and its relatively sparse leaf growth minimizes self-shading. This sparse leaf growth does not appear to reduce the turbidity of the water based on measures of PAR inside and outside of *S. pectinata* beds (Boyer unpublished data). However, species-specific effects on light conditions are not well known for this or other species in the Delta.

Studies also support that light is likely to be quite limiting to lower portions of plant tissue in dense *Egeria densa* beds. In one local experiment testing light effects, *E. densa* had 4-fold lower biomass under conditions comparable to those measured in beds in the Delta at 1 m depth (215.5 µM quanta $m^{-2}s^{-1}$) compared to light levels 2x greater (Borgnis and Boyer, unpublished data). Although Durand (2014) found an ambiguous relationship between turbidity and *E. densa* growth, he found a low probability of establishment at depths below 5 m. In a New Zealand mesocosm study, reduced light (25% reduced from 50% incident level) was found to be a more important factor controlling *E. densa* than was temperature (tested at 20, 26, and 30°C) (Riis et al. 2012). Interestingly, a Brazilian study found the highest rates of elongation for apical shoots of *E. densa* occurred under reduced light conditions (<30 µM quanta $m^{-2}s^{-1}$), suggesting a mechanism by which *E. densa* may extend its canopy upward through the water column (Rodrigues and Thomaz 2010).

Waters in the Delta have become clearer over at least the last fifty years. The delivery of suspended sediment from the Sacramento River to the Delta has decreased by about half during the period between 1957 and 2001 (Wright and Schoellhamer 2004) and this has resulted in a statistically significant (2 to 6 percent) decrease per year in suspended particulate matter between 1975 and 2005 (Jassby 2008). It is unclear whether this increase in water clarity has increased the biomass and distribution of submerged macrophytes already, or how it will influence other important factors in plant growth, including nutrients.

4.1.2 Temperature

Warm temperatures are expected to favor the establishment and growth of both floating and submersed species and to produce localized warming of waters through reduction in water flow, which in turn should benefit plant growth (Fig. 4.2A-B). However, high water temperatures within the range found currently in the Delta might limit growth of some species, and temperatures are expected to increase with climate warming (Knowles and Cayan 2002; Wagner et al. 2011). A 2012 experiment testing water temperature effects on growth of *E. densa* apical shoot sections in aquaria showed substantial increases over time in aboveground biomass, total shoot length, and mean root length at a water temperature of 22°C (the average measured in the west Delta in summer) in fresh water, with similar effects at 26°C, although much less of a biomass response (Fig. 4.3, Borgnis and Boyer in revision). In contrast, there were great reductions in all these measures at 30°C (Fig. 4.3), which is within the current range of maximum temperatures measured for the west Delta (Borgnis and Boyer, in revision). Further, testing these temperatures at a salinity of 5, which can be found in the west Delta in drought years (e.g., 2012-2014), led to a reduction in root length at all temperatures. At a salinity of 10, the negative effects of high temperature (30°C) were amplified and led to greatly reduced aboveground biomass (Fig. 4.3). As for cold temperatures, we are not aware of any local data; in other regions, night-time freezing, especially in shallow water was found to be highly stressful to *E. densa* (Leslie 1982).

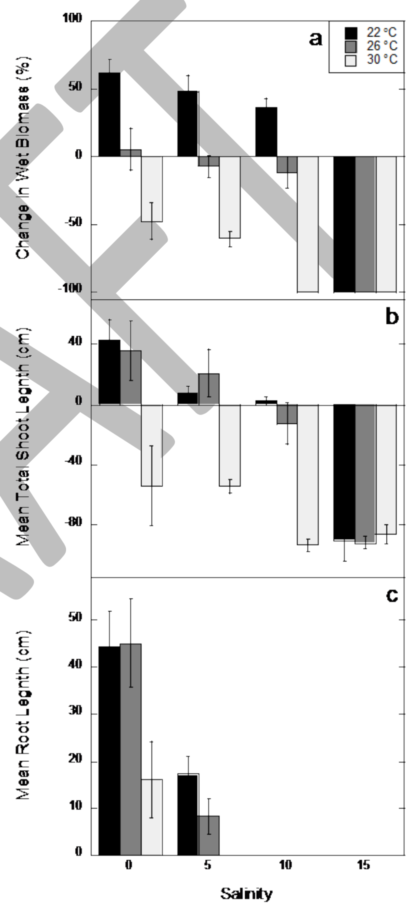

Figure 4.3. Response of Egeria densa to a range of temperature conditions applied at increasingly high salinity conditions at the end of 6 weeks in aquaria. From Borgnis and Boyer, in revision

We know of no local experiments testing temperature effects on *Eichhornia crassipes*, *Ceratophyllum demersum*, or *Stuckenia pectinata*. In other regions, *Eichhornia crassipes* has been shown to benefit from warming above ambient conditions within limits. In China, *E. crassipes* rates of relative growth and clonal propagation increased by 15% with an increase in water temperature from 24 to 26-27°C in mesocosms (You et al. 2014). However, at temperatures above 33-34 C, *E. crassipes* loses nutrients from the roots and experiences negative growth (Moran, pers. comm.). *E. crassipes* is also limited by cold temperatures in the range of 10°C (Gopal 1987; Wilson et al. 2005). Frost can cause mortality of leaves and whole plants (Bock 1969; Ueki and Oki 1979; Spencer 2005), although stem bases can survive and serve as propagules for growth in the next year (Spencer 2005). Large rafts of *E. crassipes* have been observed floating seaward from the Delta during periods of freezing night-time conditions, suggesting deterioration of the ability to remain in cohesive mats under these conditions (Foe, pers. comm.). Further, a three-week period of night-time frost in 2007 appeared to have contributed to a significant decline in *E. crassipes* in the next year (Khanna, pers. comm.).

4.1.3 Salinity

In general, species in much of the Delta experience fresh water maintained with little seasonal variation through water management practices to support potable, industrial, commercial, and agricultural uses (Moyle et al. 2010). This is in contrast to the historic condition of seasonal and interannual salinity variation prior to water management practices. In the past several years of drought, late-summer water salinities of 5 or more have reached east to the Sherman Lake region of the Delta. Salinity could further increase in the Delta through several mechanisms stemming from climate change and water management. Sea-level rise and shifts in magnitude and timing of snowmelt events are projected to increase salinity levels by 1-3 in this region by 2090 (Knowles and Cayan 2002). In addition, extended periods of drought could lead to increased salt penetration not counteracted by reservoir releases during the summer months. There is also potential for levee failures through erosion or earthquakes, leading to a higher volume of saline tidal waters reaching up-estuary. Finally, management actions that inadvertently or deliberately reduce fresh water releases during the dry season could increase salinity in this region. Summer and fall salinity has already increased in the last 25 years due to reduction in fresh water releases from water control structures (Knowles and Cayan 2002; Contra Costa Water District 2010). C&H Sugar Refining Company (Crockett, CA) has long tracked salinity in order to access fresh water for its refining process; its data show annual salinity intrusion now occurs much earlier in the year in Suisun Bay (beginning of March) compared to the early 1900s (beginning of July) (Department of Water Resources 2010).

As mentioned, *Egeria densa* is strongly limited by salinity. As in the six-week temperature-controlled aquaria experiment described above, a three-month experiment conducted in large tanks in a greenhouse in 2012 showed *E. densa* negative responses to a salinity of 5, with a 5-fold decrease in biomass relative to the freshwater treatment over the three months (Fig. 4.4, Borgnis and Boyer, in revision). At salinities of 10 and 15, mortality and decomposition occurred within three weeks. This was in contrast to 5-fold increases in shoot biomass in freshwater over the three months, and nearly 10-fold increases in the number of shoots and in root biomass (Fig. 4.4). Tissue nitrogen (N) concentration stayed constant at salinities of 0 and 5; however, tissue phosphorus (P) increased at a salinity of 5 (and thus N:P also), suggesting that P taken up could not be utilized and thus accumulated in the tissues, perhaps another indication of stress at this higher salinity.

Of all aquatic macrophyte species found within the Delta, *Stuckenia pectinata* is expected to have the greatest tolerance for salinity. This assumption is due in part to its nearly monotypic distribution in waters that can reach salinities of 15 within Suisun Bay. Further, in six weeks in greenhouse mesocosms, *S. pectinata* biomass accumulated greatly (~4x initial) at salinities of 0 and 5, doubled at 10, and was unchanged at 15 (Fig. 4.4; Borgnis and Boyer, in revision). Increases in both N and P concentrations in tissues at higher salinities (Fig. 4.4) suggests an inability to utilize all available nutrients, and perhaps the accumulation of N as “compatible solutes” to balance water potential as is common in saline wetland plants.

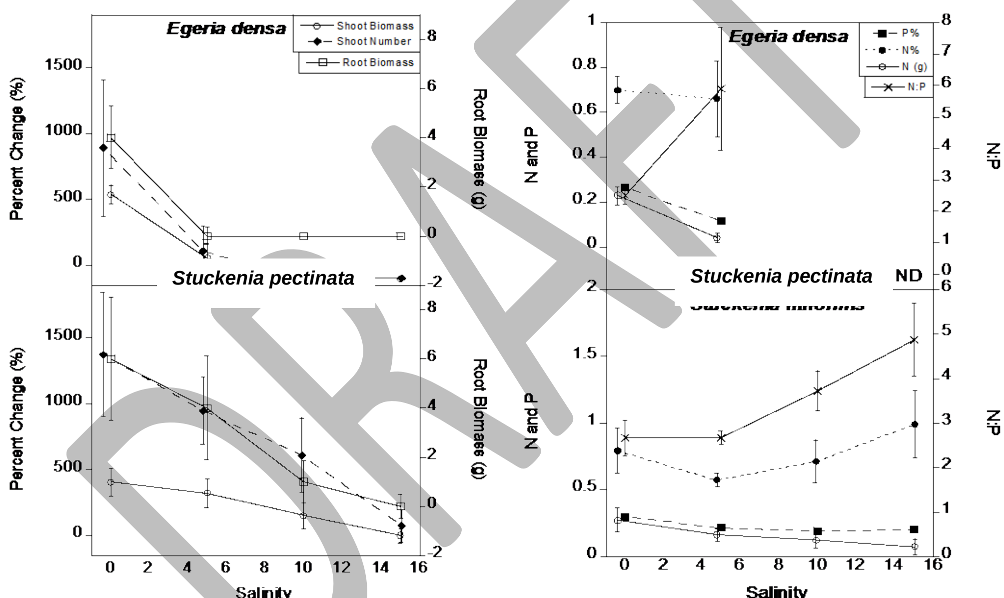

Figure 4.4. Salinity effects on growth characteristics and nitrogen and phosphorus content and ratio of Egeria densa *and* Stuckenia pectinata *at the end of mesocosm experiment that ran June-August 2012. ND = no data;* E. densa *tissue nutrients could not be measured at the higher salinities due to insufficient tissue availability. From Borgnis and Boyer, in revision*

We are not aware of any local studies of salinity tolerance on *Ceratophyllum demersum* or *Eichhornia crassipes*. Studies in other regions have found that *E. crassipes* undergoes stress at salinities as low as 2.5 (Haller et al. 1974) and that salinities above 6-8 are lethal (Muramoto et al. 1991; Olivares and Colonnello 2000).

4.1.4 Dissolved inorganic carbon

Floating vegetation should be able to access adequate carbon dioxide to fuel photosynthesis; however, availability of dissolved inorganic carbon (DIC) can be an important limiting factor to submersed species. The forms of carbon dissolved in the water are determined by pH (Barko and Smart 1981; Sand-Jensen 1989). Although CO_2 is the form of DIC preferred by all autotrophic organisms (Raven 1970), drawdown of CO_2 leads to increased pH. This is because CO_2 in solution is in equilibrium with carbonic acid (H_2CO_3), which becomes more common, leading to removal of protons from the water (thus a higher pH). This, in turn, has an effect on the relative concentrations of the other DIC forms in the water and bicarbonate (HCO_3^-) becomes the primary form of DIC available (Sand-Jensen 1989; Santamaria 2002). Species that can utilize bicarbonate efficiently should have an advantage in the waters of the Delta. Both *Egeria densa* and *Ceratophyllum demersum* are able to efficiently utilize bicarbonate as a DIC source (Cavalli et al. 2012), which may partly explain their success within the Delta, with the heightened pH in dense beds leading to further advantage over time through positive feedback (Fig. 4.2A). We are not aware of pH measures within macrophyte beds in the Delta, but heightened pH and diurnal swings in both pH and CO_2 would be expected to be greatest within dense beds of *E. densa* and in settings with limited water flow.

4.1.5 Nutrients

The primary nutrients that limit plant growth are nitrogen (N) and phosphorus (P). Limitation is typically determined by adding one or more nutrients to ascertain if the potential rate of net primary production has been achieved (Howarth 1988); in other words, if the plant grows with added nutrients, then it has greater potential for production than what its ambient nutrient environment allows. At temperate latitudes, phosphorus is generally considered the primary limiting element to system primary production in freshwater, and nitrogen is considered the primary limiting element in marine systems, although there is variation in this pattern (Smith 1984). N may be less limiting in freshwater due to a greater importance of N fixation there (Howarth et al. 1995, 1999; Paerl et al. 1995), and a greater efficiency of sediments in sequestering P than in marine systems (Caraco et al. 1990); however, both N and P have been shown to be important in estuaries (McComb et al. 1981; D'Elia et al. 1986) under different conditions and seasonally (Conley 2000).

The San Francisco Estuary is an example of a system replete in both N and P, and yet depauperate in phytoplankton production (Cloern 2001). The annual loading rates of both N and P are higher in San Francisco Estuary than in the Chesapeake, and yet large phytoplankton blooms and mortality common in Chesapeake, followed by large drawdowns in dissolved oxygen concentration, do not typically occur in the San Francisco Estuary (Cloern et al. 2001). Thus, San Francisco Estuary is not considered to be a eutrophic system in terms of algal production; phytoplankton may be limited by high levels of turbidity, abundant consumers including introduced clams (Jassby and Cloern 2000), and possibly by the ratios of species of N available (i.e., ammonium versus nitrate, Wilkerson et al. 2006).

Comment [KB6]: John Durand said "limited at times in N Delta off Sac plume" – need clarification or reference

Although adequate nutrient supply is necessary to fuel growth of macrophytes in the Delta, the degree to which nutrients trigger or exacerbate extensive growth of the invasive *Egeria densa* and *Eichhornia crassipes* (and now *Ludwigia* spp. as well) within Delta waters is unclear. Acreage of all these invasive macrophytes has expanded in recent years, and especially during the time between two mapping events in 2008 and 2014 (Khanna and Ustin, unpublished data). Although there has been an increase in NH_4^+ and a decrease in the N:P ratio over a 30 year period through 2006, especially in the upper Sacramento River, this trend was not evident in the last decade of that time period (Glibert 2010; Fig. 4.5). A closer look at the last decade (through 2013) shows no trends in any form of inorganic nutrients or N:P ratios in the central Delta region (Berg and Sutula 2015, Figure A-1 through A-4). Thus, it does not seem that overall increasing acreages of invasive macrophytes can be related to changes in ambient dissolved inorganic nutrient concentration, form, or ratios during the same time period.

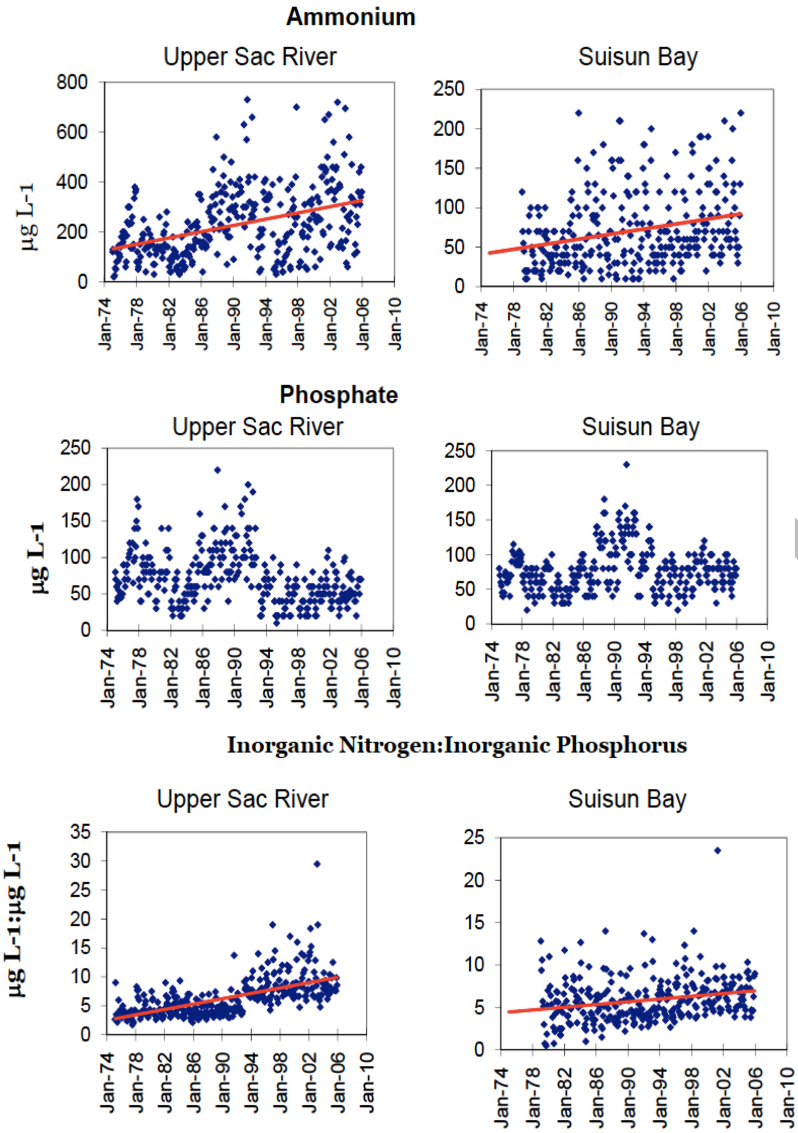

Figure 4.5. Patterns in ammonium, phosphate, and ratios of inorganic N to P over time at two locations, upper Sacramento River and Suisun Bay. From Glibert 2010.

Water nutrient concentrations vary across the geographical extent of these species, with at least a 3-fold difference in all three of the primary inorganic nutrient forms, ammonium (NH_4^+), nitrate (NO_3^-) and phosphate (PO_4^+) from the upper Sacramento River to Chipps Island (Foe et al. 2010; Figs. 4.6, 4.7).

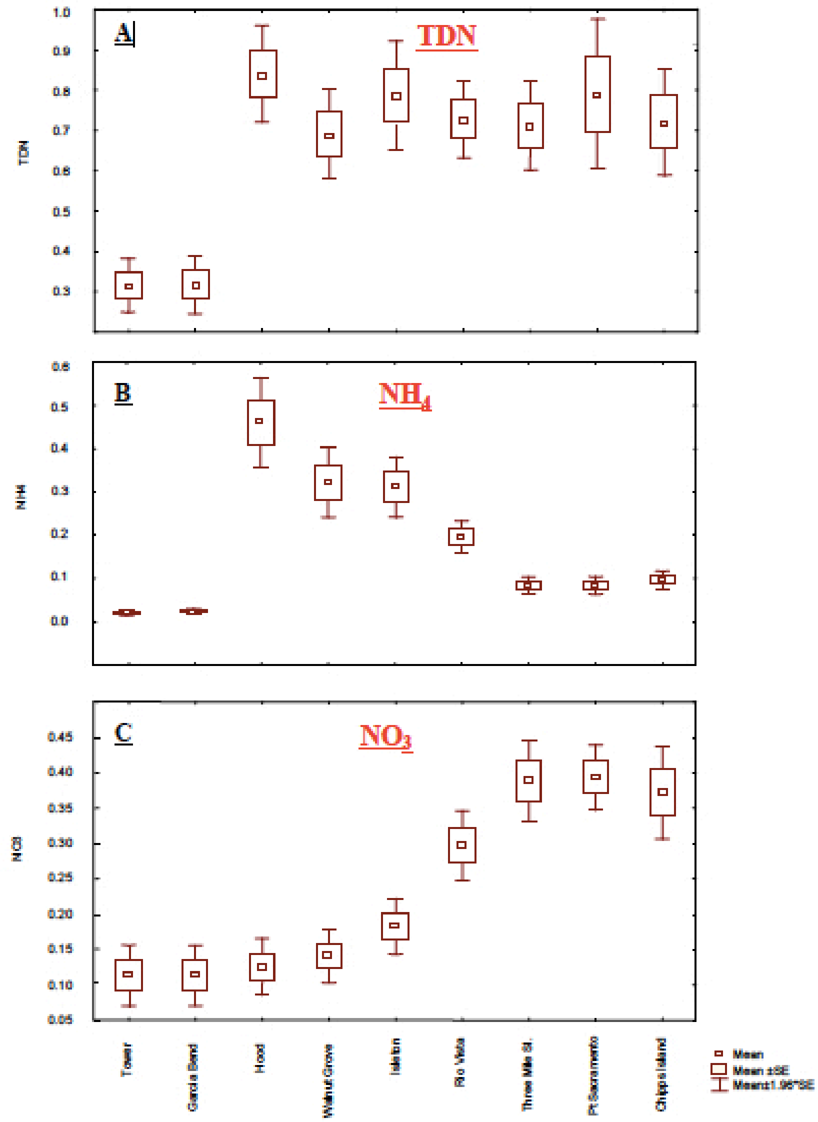

Figure 4.6. Mean annual total dissolved nitrogen (TDN), NH_4 and NO_3 concentrations in the Delta between Tower Bridge (north Sacramento River) and Chipps Island (Suisun Bay) between March 2009 and February 2010. Tower and Garcia Bend sites are above the discharge of the Sacramento River Water Treatment Plant. From Foe et al. 2010.

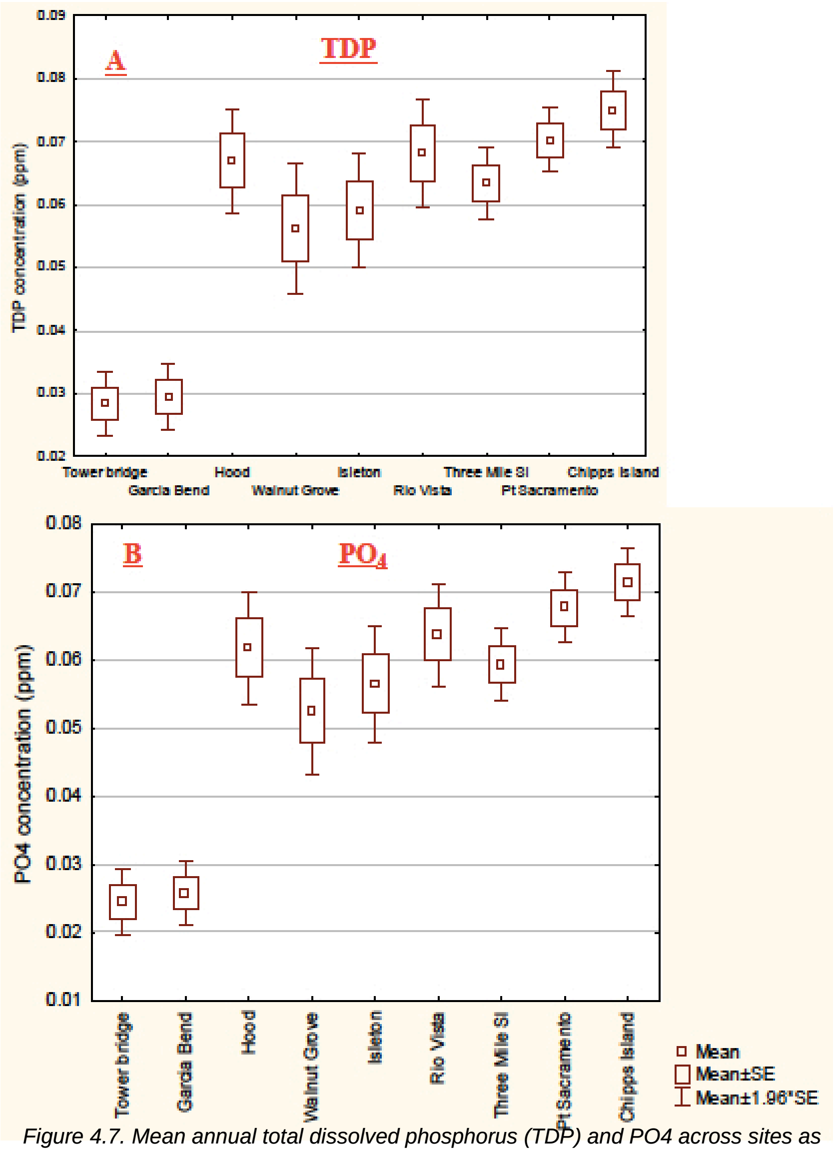

Figure 4.7. Mean annual total dissolved phosphorus (TDP) and PO4 across sites as in Fig. 4.5. From Foe et al. 2010.

It is possible that acreages of these species could be examined in relation to nutrient supply to determine if there is a correlation between changes in abundance and nutrient patterns at specific locations, but it would be difficult to tease apart other co-occurring patterns in environmental conditions that may vary with nutrients.

Egeria densa is able to take up nutrients through its leaves and roots, thus accessing water column nutrients from both the water column and the sediment. Studies differ on whether it preferentially takes up nutrients from its roots (Barko and Smart 1980) or shoots (Feijoo et al. 2002). *Eichhornia crassipes* accesses nutrients through its roots hanging at the surface of the water column (Klumpp et al. 2002; Rommens et al. 2003). Although many experiments have tested the effects of nutrients on phytoplankton growth under different scenarios of light, temperature and other variables in the Delta (e.g., Wilkerson et al. 2006), we know of no comparable local experiments conducted on aquatic macrophytes.

Researchers in other regions have evaluated nutrient limitation of *E. densa* through experiments in which nutrients were added to test the plant's response. In *E. densa*'s native range in highly enriched Pampean streams in Argentina, biomass and nutrient content were positively correlated with nutrient concentrations (phosphate and ammonium) in the water and in sediments (as total N) (Feijoo et al. 1996). An experiment by that same group found ambient levels of phosphate (0.3 mg l^{-1}) led to significantly greater biomass than phosphate at half of ambient concentrations (Feijoo et al. 2002). In a separate experiment, they found that ammonium was absorbed more readily than nitrate (added at ambient concentrations of 6 mg DIN l^{-1}, separately), leading to higher concentrations of tissue N with ammonium; however, this did not translate to differences in biomass (Feijoo et al. 2002). A comparison across the two experiments found phosphate was more readily absorbed by *E. densa* than nitrogen in either form, and that water column uptake was greater than from sediments (Feijoo et al. 2002). A study in Florida also found *E. densa* to prefer ammonium over nitrate when both were present in the water in equal amounts at concentrations considered to be non-limiting (10.5 mg l^{-1} of each DIN source, plus phosphate at 3 mg l^{-}1, as found in sewage effluent, Reddy et al. 1987). In a separate experiment, these authors varied concentration of ammonium and phosphate (range of 1-4 mg N and 0.2 to 0.8 mg P l^{-1}, respectively); although they did not report biomass data, they noted that biomass was *greater* at low nutrient concentrations than at high. N and P removal rates were estimated to be 186-408 mg N m^{-2} day^{-1} and 122-228 mg P m^{-2} day^{-1} from the water column (Reddy et al. 1987). *E. densa* uptake of both nutrients was similar in summer and winter experiments. A Florida mesocosm experiment repeated in two different seasons (April-June and October-December) found no effects of fertilizer (N:P:K of 15-9-12 in slow release fertilizer) added to the sediment in a range of concentrations from 0 to 4 kg/g sediment) on *E. densa* biomass (Mony et al. 2007).

Taken together, these studies of *E. densa* suggest that nutrient uptake from water may be preferred over uptake from sediment, that ammonium may be preferred over nitrate, and that phosphate may be more readily absorbed than either form of N. The tests of water column nutrient effects in all the above studies were conducted at very high concentrations, which may explain the limited growth responses. Although concentrations vary among sites in the Delta, typical DIN levels are 0.5 mg l^{-1} and DIP levels are 0.06 mg l^{-1} (annual means of ~monthly sampling in 2009-2010; Figs. 4.6, 4.7; Foe et al. 2010), with an annual average as high as 1.43 mg l^{-1} DIN and 0.18 mg l^{-1} DIP at one site (Foe 2010). However, the studies described in the previous paragraph evaluated *E. densa*'s responses under higher ambient nutrient conditions and thus they tell can us little about water column nutrient thresholds for macrophyte biomass expansion in the Delta. In addition, little is understood about the role that dissolved organic nutrients may play in supporting macrophyte growth. Moreover, we suspect rooted species like *E. densa* with the capability of accessing nutrients from both the water column and the sediments would be very difficult to manage by only reducing water column nutrient supply, especially in quiescent areas where dead biomass can accumulate and possibly provide an extended period of remineralizable nutrients. Further, the positive feedback of declines in dissolved oxygen making sediment-bound P more available (see Chapter 3) suggests that this important nutrient will continue to be sourced from the sediments (Cornwell et al. 2014), especially in places where decomposing macrophyte tissues accumulate.

Eichhornia crassipes, with access to nutrients only from the water column, is perhaps a simpler case. A number of studies have shown *E. crassipes* to readily absorb added N (Carignan and Neiff 1994; Heard and Winterton 2000; Reddy et al. 1989, 1990; Moran 2006) and to sometimes be limited by P (Srivastava et al. 1994; but see Moran 2006, who did not find an association between DIP and P uptake). In a mesocosm study on *E. crassipes* in China, nutrient additions to lake water comparable in nutrients to the Delta (0.6 mg l^{-1} total N and 0.05 mg l^{-1} total P), raising N to 5 mg l^{-1} (using NH_4NO_3) and P to 0.5 mg l^{-1}, led to 30% increases in both relative growth rate and clonal propagation rate (You et al. 2014). Notably, the same elevated N level combined with a much higher P enrichment (1.0 mg l^{-1}) led to 150% increases in these measures relative to ambient conditions simulated. In that same study, warming by 2-3 degrees had a much smaller positive effect on growth rate (15%) and some effects of elevated temperature (increased shoot:root and foliar N) were found only when nutrient levels were also elevated (You et al. 2014). A study that explored water N concentration in relation to *E. crassipes* growth rates (Aoyama et al. 1986; see review and modeling by Wilson et al. 2005) suggests that *E. crassipes* growth rates in the Delta could be reduced with lower DIN concentrations than are typically found there (0.5 mg l^{-1}, Foe et al. 2010). This work also estimated that N becomes limiting for E. *crassipes* growth at an N:P ratio in water of <7 (Wilson et al. 2005); assuming 0.5 and 0.06 mg l^{-1} DIN and DIP in Delta waters on average (Foe et al. 2010), respectively, an N:P ratio of about 8 suggests that N supply is not currently limiting. Although water column nutrients are the only source available to *E. crassipes*, sediment fluxes can supply both N and P (the latter enhanced by low oxygen conditions) to the water column. Hence, while management of water column nutrient supply might seem to be a straightforward solution that could reduce *E. crassipes* abundance, perhaps more easily than for *E. densa*, biogeochemical coupling with the sediments must also be considered.

4.1.6 Flow, residence time, substrate stability, and slope

Flow velocity and residence time of water within a given area are expected to influence both floating and submersed species. Propagules need to be able to stay in place to initiate bed establishment, which succeeds to a greater degree in more protected areas. Two studies fround flow rates above 0.3 or 0.49 ms^{-1} limiting to establishment of *Egeria densa* (Durand 2014 and Hestir 2010, respectively). Substrate stability is necessary for submersed plant establishment and persistence, and larger grain size (sand) can lead to less stable bed conditions, especially under higher flow regimes. Development of an aquatic plant bed slows flow in the immediate vicinity, a positive feedback loop that further supports bed development. Although the draft conceptual model of Anderson (2008) indicates the importance of substrate stability, it does not indicate the importance of this positive feedback (Fig. 4.2A). Densely growing submersed macrophytes like *Egeria densa* can reduce flow by 40% (Wilcock et al. 1999; Champion and Tanner 2000), favoring their continued presence and spread within the area. However, higher flow is important to dispersal of propagules of all aquatic macrophytes to new areas (Fig. 4.2A) and water movement is essential for growth by bringing nutrients and dissolved carbon to the leaves by mass transport.

Depth and slope of shores can also limit submersed species (Fig. 4.2A). *Egeria densa* can grow to depths of 6 m (Carrillo et al. 2006) and 40% slope, but this seems to be the extreme (in tropical, high elevation lakes). *Eichhornia crassipes* vegetative propagation is not limted by water depth, but propagules accumulate along shores due to greater protection from washing out. Although sexual reproduction contributes little to population growth in the Delta, germination and seedling growth require shallow water over gentle sloping shorelines to maximize light availability (Barrett 1980).

4.1.7 Interactions with other submersed or floating species

A factor not summarized in the draft conceptual models of Anderson (2008) is interaction among species of aquatic macrophytes. Several recent studies suggest these could be quite important in determining the abundance of some species or guilds of species. For example, experimental work in mesocosms suggests that *Egeria densa* has strong negative effects on *Stuckenia* sp. growth under fresh water conditions. When grown together with *Egeria densa* in fresh water, *Stuckenia* sp. produced 75% less biomass than in monoculture, and significantly more nodal roots, suggesting increased nutrient foraging (Fig. 4.5, Borgnis and Boyer in revision). At a salinity of 5, a decline in *E. densa* performance (see above) coincided with a doubling of *Stuckenia* sp. shoot

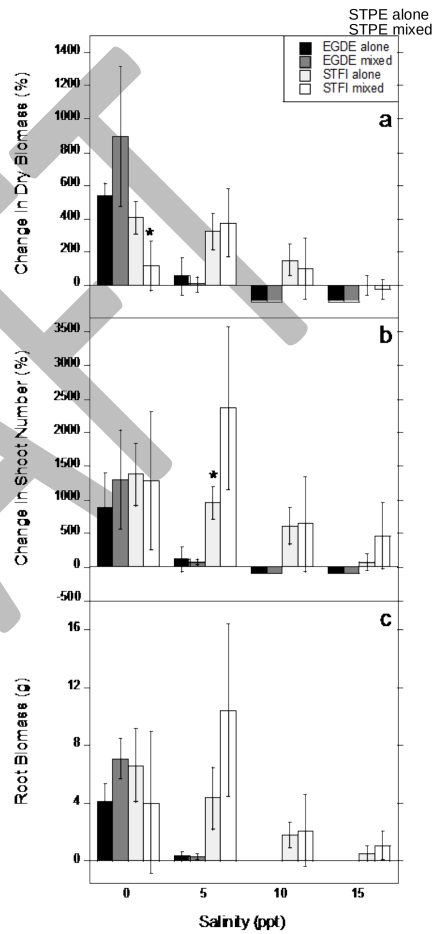

Figure 4.5. Effects of salinity on growth characteristics of Egeria densa *(EGDE) and* Stuckenia pectinata (STPE)*, grown separately and together, at the end of a mesocosm experiment running June-August 2012. From Borgnis and Boyer, in revision*

density. These results suggest that *S. pectinata* might be more abundant in the fresh waters of the Delta in places where *E. densa* currently dominants.

There may be other possibilities of important interactions within the submersed plant community. As previously mentioned, *Egeria densa* maintains substantial biomass during the winter, perhaps increasing its competitive ability among species that undergo winter senescence, such as *Stuckeina pectinata*. However E. *densa* may facilitate other species in some cases. In one study, *Ceratophyllum demersum* was found to occur more frequently with other species, especially *Egeria densa*, than it occurred on its own (Santos et al. 2011), suggesting it may derive some benefit from other species.

In addition, remote sensing data tracking changes in the coverage of the floating species *Eichhornia crassipes* indicated a large loss of submersed species with an increase of 25% in *E. crassipes* and conversely a large increase in submersed species with 25% decrease (Fig. 4.6, Khanna et al. 2012). The possibility that one of these invaders will replace the other and vice versa with management is an important issue to consider. In contrast, there were no consistent effects on other floating species: the native *Hydrocotyle umbellata* or the introduced *Ludwigia* spp. (Fig. 4.6). A conceptual model was developed to show the hypothesized relationships between *E. crassipes* and submersed vegetation with succession and treatment (Fig 4.6). An interesting new trend of reduced *H. umbellata* accompanied by large increases in *Ludwigia* spp. suggests that there may be feedbacks between these two species as well (Khanna and Ustin, unpublished data).

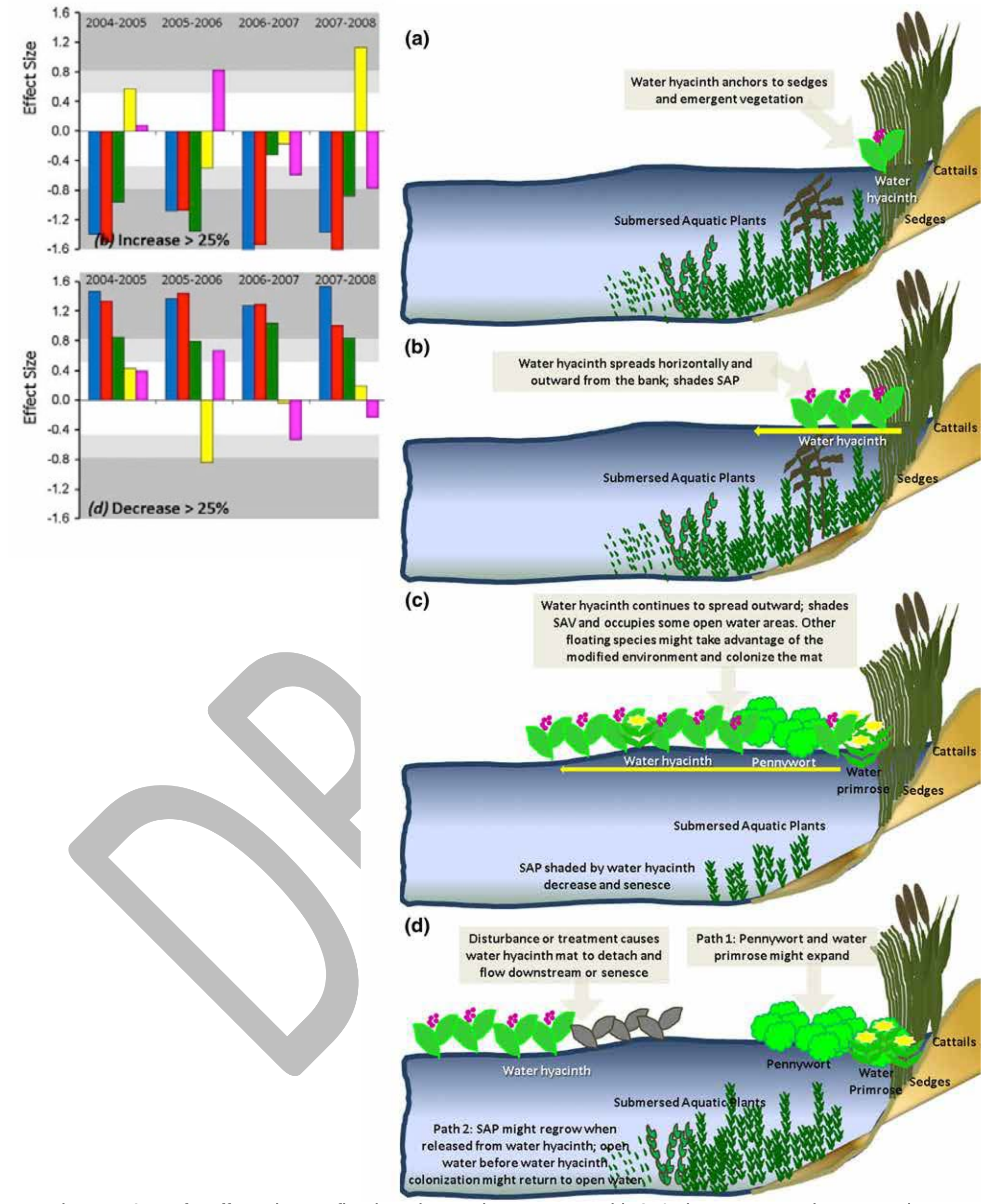

Figure 4.6. Left: Effect sizes reflecting change in coverage with 25% increases or decreases in water hyacinth (Eichhornia crassipes) from remote sensing data (dark region of background indicates a strong effect). Changes are shown for water (blue), submersed vegetation (red, predicted to be primarily Egeria densa), emergent and senescent plants (green), native pennywort Hydrocotyle umbellata (yellow), and introduced water primrose (Ludwigia spp., pink). Right: Conceptual model of successional pathways of E. crassipes growth and expansion, with effects on other floating and submersed plants. From Khanna et al. 2012

4.1.8 Chemical, mechanical, and biological control

Herbicide application has been the most common means of attempted control for both *Egeria densa* and *Eichhornia crassipes* to date (Anderson 1990, DBW 2005). Legal challenges to herbicide control have led to new permitting and monitoring requirements (Siemering et al. 2005), and a re-evaluation of alternative control methods (Greenfield et al. 2007).

Mechanical removal of *Egeria densa* has been attempted in the Delta, but tends to produce fragments that then can become propagules for further spread locally and in distant locations through water movement (Anderson 2003). Such harvesting also has the potential to remove or damage non-target organisms. Mechanically gathering and harvesting *Eichhornia crassipes* can be effective in limited areas, but it is expensive to remove the heavy masses of plants with very high water content (Gopal 1987). Shredding of this species using shredder boats and leaving the plant material in place may be one option, although the resulting biomass and source of remineralizable nutrients as well as dissolved oxygen implications are both concerns in areas with limited flow (Greenfield et al. 2007; see above). Further, such shredding can leave viable propagules that can survive and regrow (Spencer et al. 2006). Benthic barriers have been used to limit small infestations of *E. densa* around high use areas such as docks, boat launches and swimming areas in other regions but have not been used in the Delta to our knowledge.

Comment [KB7]: Cite – Llaban suggested Biology and Control of Aquatic Plants. A Best Management Practices Handbook

There is an extensive literature on the use of biological agents as controls for *Eichhornia crassipes*. There are two commonly used weevil species from the plant's native range in use for biological control, in the genus *Neochetina* (Sosa et al. 2012). Typically, mechanical or chemical treatment is used first, making initial conditions more manageable for biological control (Adekoya et al. 1993). In the Delta, several species intended for biological control of *E. crassipes* were introduced in the early 1980s; of these, the weevil *Neochetina bruchi* has become established but does not appear to have much impact (Stewart et al. 1988). Although this weevil is likely to have its nutritional needs met through adequate plant nutrient levels in the Delta (Spencer and Ksander 2004), its immature stages have poor survivorship during winter conditions (Akers and Pitcairn 2006). The US Department of Agriculture (USDA-ARS) and the California Department of Food and Agriculture (CDFA) are investigating other potential biological control agents, and are beginning to release a planthopper, *Megamelus scutellaris* for *E. crassipes* control (P. Moran, USDA-ARS Exotic and Invasive Weeds Research Unit, Albany, CA, pers. comm.). This planthopper is considered to be sufficiently host-specific in Florida, where it is now widely established, and impact evaluations there are ongoing (Tipping et al. 2014a; Moran, pers. comm.).

To date, besides the above biological control attempts in the Delta on *E. crassipes*, no other introductions have been made for control of other invasive macrophytes. Biological control studies are underway for *E. densa* under lab conditions; an ephydrid fly larva is one species being evaluated (D. Dubose, USDA-ARS, pers. comm.).

Although biological control methods may be desirable to avoid the concerns of non-target species effects of chemical application, the resulting biomass can still be an issue to contend with. *Neochetina* spp. weevils reduce buoyancy of *Eichhornia crassipes,* making it sink to the bottom and decompose (Wilson et al. 2007). As with chemical control or natural causes of plant death (e.g., freezing temperatures), if there is mortality and accumulation of dead material, decomposition can lead to a drawdown of oxygen and a release of nutrients, mainly in quiescent areas where the material is not washed out (Greenfield et al. 2007). Further, biological control has been shown to reduce the size of *E. crassipes* plants over several generations, which could reduce the biomass of live plants that can lead to low oxygen conditions beneath the floating mats (Tipping et al. 2014b).

4.2 Relative Importance of Nutrient Subsidies Versus Other Factors in Promoting Observed Trends

Our review indicates that there are a number of important factors that affect the biomass and distribution of nuisance aquatic species. There are a few factors that can lead to large losses of biomass in a short period of time, including increased salinity for *E. densa* and *E. crassipes* and freezing temperatures for the latter. Two papers reported on state shifts resulting from dramatic losses of these two species. As described above, *E. crasspes* suffered a major decline largely attributed to reduced light due to extended cloud cover (during El Niño years) in Lake Victoria in Africa (Williams et al. 2005, 2007). *E. densa* disappeared from a wetland in its native range in southern Chile, probably due to dessication exascerbated by low rainfall and cold temperatures (Marin et al. 2009). It is possible that there are management actions that could be used in some areas of the Delta to control these species to some degree. For example, water levels could be controlled in some locations, in order to attempt to dessicate *E. densa*, and salinity could be permitted to intrude for brief periods of time if that were politically acceptable (Moyle et al. 2010), which could shift west Delta *E. densa* stands to the native *Stuckenia pectinata*. Species interactions are also worth considering in manipulations; e.g., are there management actions that could shift composition toward native or desirable species? However, there is also the possibility of a "zero sum game" if managing *E. crassipes* leads to further invasion by *E. densa* and vice versa, or other undesirable species are benefitted through a management action.

Nutrients are certainly important to the growth of all plant species and our review suggests that the nutrient levels currently found in the Delta are probably not limiting these plants. Studies of nutrient addition to *Eichhornia crassipes* show clear signs of a direct relationship of water column nutrients to accumulation of biomass as well as clonal propagation, and it may be possible to reduce growth rates through nutrient reductions. However, studies of *Egeria densa* biomass at realistic nutrient levels for the Delta are very limited, and thus do not provide convincing evidence that a reduction in water column nutrients will result in a reduction in *E. densa* production. Further, for both these species, we have very limited understanding of the relative importance of new nutrient supply versus the cycling of nutrients within beds, including the release of P from sediments within macrophyte beds (Cornwell et al. 2014). Finally, have very limited information on the relative importance of nutrients versus other factors in controlling growth and biomass expansion of any of the nuisance invaders within the Delta. The fact that DIN, DIP, and N:P have remained quite steady over the last decade, while there have been great expansions in areal extent of *E. densa*, *E. crassipes* and *Ludwigia* spp. during the latter part of this period, suggest that nutrient management alone will not be sufficient to control any of these species.

5. Recommendations

The goal of this review is to synthesize available information to provide insight into major factors controlling the expansion of invasive floating and submerged aquatic vegetation in the Delta. The review addressed three major questions:

1. How does submersed and floating aquatic vegetation support or adversely affect 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 found that the lack of routine monitoring of aquatic macrophytes greatly hindered our ability to summarize, with confidence, the status and trends of floating and SAV in the Delta (Question 2), and to what extent nutrients versus other factors were controlling their occurrence (Question 3). Given this finding, our recommendations are focused on three principal actions:

1. Implement routine monitoring of macrophytes as well as the major factors that control them.
2. Develop and use a biogeochemical model, coupled with routine monitoring and special studies, to understand the spatial and seasonal nutrient and organic carbon budgets vis a vis major sources of nutrients fueling floating and SAV growth.
3. Conduct a literature review and a pilot research program in floating and SAV control programs.

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 on-going rigorous evaluation of patterns and trends. Monitoring should be comprised of a combination of remotely sensed areal coverage and field-based transects to estimate biomass or, ideally, net primary production (through repeated measures of biomass over time to determine rates of turnover). Despite recent advances in remote sensing to include image spectrometry (i.e., hyperspectral remote sensing), problems with misclassification among non-native SAV as well as poor detection of species that occur in smaller patches (e.g., *Stuckenia* sp.) suggest that transect and quadrat monitoring is also needed to follow trends in species composition in space and time. 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 workplan 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. Early actions should include the development of a workplan to lay out the key indicators and cost estimates required for monitoring. 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 under way, 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 dead material into additional growth in areas with high residence time. A current USDA-ARS progam on integrated control methods for both *E. densa* and *E. crassipes* could help to inform the proposed review.

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7.0 Appendices

7.1 Comment Matrix and Responses to Science Working Group

Author	Page	Comment	Response
Conrad	ii	Executive Summary, first paragraph, second sentence - What type of impairment? Ecosystem?	added word "ecosystem"
Conrad	ii	Executive Summary, first paragraph, last sentence - Only three (major) questions follow (not four).	fixed
Conrad	ii	Executive Summary, Finding#2: Lack of a routine monitoring program hampers our ability to discern recent spatial and temporal trends. - This seems like a recommendation rather than a finding. The finding is that Egeria and water hyacinth dominate the macrophyte community in the Delta and may be expanding. The lack of adequate monitoring is addressed in your recommendations below so I suggest removing this sentence here.	changed the findings section to incorporate this
Conrad	iii	Executive Summary, Finding#5: first sentence - Sea level rise should also be mentioned here, perhaps?	did not mention; much less important to species that can grow in range of depths than other factors
Conrad	1	Under Chapter 1, Section 1.1, fourth sentence: The Delta is widely recognized as in "crisis"…" - Incomplete sentence.	fixed
Conrad	3	Under Chapter 1, Section 1.2, Second paragraph - Re-start numbering (of key questions) at #1.	fixed
Conrad	4	Under section 2.1 , the first two sentences were highlighted by the commenter but no comment provided.	not sure why highlighted by reviewer either
Conrad	11	Figure 2.5 caption - The caption says that the Google Earth imagery was "digitized and ground trothed." How was the ground-truthing conducted? It seems hard to believe that a species-level determination of submersed vegetation can be done from visual review of Google Earth imagery, especially given that analysis of hyperspectral imagery was not always reliable for species determination of SAV. The reference for this is Boyer et al. 2015, which is not provided in the Google Drive of references. Is it possible to see this information.	additional explanation added. Species level is pretty easy to determine within Suisun Bay, as ground-truthing (visiting all areas) by boat, and performing rake sampling in a subset of these areas confirmed that Stuckenia pectinata is nearly mono-typic there. In the Delta where there are many more species, this methodology does not work well as described by Ustin research group. Yes, all references will be added to the Google Drive.
Conrad	12	4th paragraph, reference to Breitler 2014 - This citation is not provided in the Literature Cited.	fixed

Conrad	13	Second paragraph on *Stuckenia sp*., first sentence - See comment above on Fig. 2.5. Was Stuckenia coverage in 1993 and 2002 also ground-truthed?	No, it was not. Additional explanation added that we assumed that Stuckenia was the only species present then as in 2011-2012 time period. The distnct growth form of Stuckenia can be seen in the previous images
Conrad	15	Section 3.1, first paragraph, highlighted sentences from "In contrast, dense canopies... to "...leading to predation on smaller adult and juvenile native fish" - Some of the following paragraph (e.g., highlighted passage) reads as if these conceptual ideas have been well established. Not the case for all of these assertions. Suggest revising the language to be less absolute.	Revised to clearly state where conceptual ideas have not been backed up by data.
Conrad	16	Under section 3.1.1, first paragraph, fourth sentence "*E. densa* sheds some biomass in winter but does not fully senesce (Fig. 2.2) - Santos et al. 2011 may be another reference to use for this assertion.	Added this reference
Conrad	17	Section 3.1.3 - Consider re-naming this "Effects on hydrodynamic and sediment processes" or some version of this. "Habitat" can mean a lot of things- from substrate to food web to water quality. I expected this section to address vegetation effects on water quality given that it addressed suspended sediment. Also, it seems more intuitive to discuss effects of vegetation on the physical habitat (like water velocity) and water quality before discussing food web effects. Right now the organization discusses food web ("trophic support") in the middle of these physical aspects.	Revised the names and order of the sections in this chapter.
Conrad	17	Under section 3.1.3, third sentence, "Submerged plants may also …" - I think Shruti Khanna's 2012 paper present a conceptual model that expresses this idea	yes, cited and this is discussed in detail in chapter 4
Conrad	18	Under section 3.1.3, last paragraph on floating vegetation - This is a very short section on habitat alteration by floating vegetation. Check Shruti Khanna's paper for more detail that could be fleshed out here…	additional detail added.
Conrad	18	Under section 3.1.4, first paragraph, first sentence - A useful reference that could be included in this synthesis is: Schultz, R., and E. Dibble. 2012. Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: the role of invasive plant traits. Hydrobiologia 684:1-14.	thanks, added the reference.
Conrad	19	Under section 3.1.4, Second paragraph under *Eichhornia crassipes*, 2nd sentence - Awkward sentence, should be revised. Shift invertebrate	sentence revised

		foods available relative to what?	
Conrad	19	Under section 3.1.4 third paragraph under Eichhornia crassipes - This section seems fairly brief, given the amount of published work on the subject. To help readers process the host of effects that aquatic veg can have on water quality, it may be useful to deal with each water quality parameter one by one, and highlight the important results (e.g. subsections for DO, pH, nutrients. And what about temperature? It seems that should bediscussed as well if there is literature suggesting the AV may have effects. Examples help too…	Each effect now discussed one by one.
Conrad	19	Under section 3.1.5. Changes in Water Quality, 1st paragraph, first sentence - These effects should be described in more detail here, with citations. I expected the rest of this paragraph to delve into effects on DO, but instead the next sentence shifts gears into nutrients.	More detail and citations added.
Conrad	19	Under section 3.1.5. Changes in Water Quality, 1st paragraph, 2nd sentence - Interesting…is there a citation for this?	yes, added citations
Conrad	20	Under section 3.1.5 2nd paragraph, 1st sentence - Does SAV contribute DO or limit it? There are diurnal swings in DO in dense Egeria beds.	expanded this section and discussed diurnal swings
Conrad	20	Under section 3.1.5, 2nd paragraph, 1st sentence (Meerhoff et al. 2003) - This reference is not listed in the Literature Cited section.	fixed
Conrad	24	Under section 4.1.1 Light, 2nd paragraph, last two sentences -Seems like it's worth noting here that rigorous study of species-specific effects on local water quality conditions (such as turbidity) have not been done- perhaps this is an area worthy of more study?	yes, added this
Conrad	24	Under section 4.1.1. Light, third paragraph, second sentence - The difference between treatments in the study described is unclear in this sentence. 2x greater…depth…light?	clarified in the text
Conrad	24	Under section 4.1.1 Light, third paragraph, last sentence - Again, the conditions tested in this experiment are not completely clear in this sentence. Why not state what the light exposure treatments were?	light exposure treatments now given

Conrad	24	Under section 4.1.2 Temperature, reference for Knowles and Cayan 2002 - This reference is missing in the literature cited section. Also, a more recent reference that projects Delta water (rather than air) temperatures is: 1. Wagner RW, Stacey M, Brown LR, Dettinger M (2011) Statistical models of temperature in the Sacramento-San Joaquin Delta under climate-change scenarios and ecological implications. Estuaries and Coasts 34: 544-556.	added this citation
Conrad	25	Under section 4.1.3 Salinity, first paragraph, first sentence - This first paragraph provides helpful background on how this aspect of water quality responds to current management practices and how it has been changing over time. It also puts the Delta plant life in context. I think this would be nice to do for light (i.e., turbidity) and for temperature as well. There are several papers that discuss a trend of water clearing in the Delta. You already do this to some extent with temperature, but it could be expanded a little (see above comment for an updated reference).	did some expanding of these sections
Conrad	25	Under section 4.1.3 Salinity, first paragraph, sentence related to summer and fall salinity in last 25 years due to management of fresh water - Reduction?	yes, reduction
Conrad	26	Under section 4.1.3 Salinity, second paragraph, reference to Figure 4.4 - I find the axes below of % change a bit confusing. What is the reference condition? What does 1000% change at 0ppt mean?	change from initial conditions over 3 month experiment. Tried to make this more clear in the text.
Conrad	27	Under section 4.1.3 Salinity, first paragraph, second sentence -Similar to (Engle's) above comment: I understand this text, but I don't see this message reflected in Fig. 4.4. It looks like a declining trend in Stuckenia biomass with increasing salinity.	there was no change in biomass at a salinity of 15 over the course of the experiment. There was a great increase in biomass at all lower salinities. Yes, there is a declining biomass with increasing salinity.
Conrad	27	Under section 4.1.3 Salinity, second paragraph - Given that there is little detail above on the distribution of these species, I'm not sure what this surmising is based on.	added citations for tolerances
Conrad	27	Under section 4.1.4, first paragraph, second sentence - And what are primary factors determining pH in the Delta?	did not address this -- out of my scope
Conrad	28	Under section 4.1.5, third paragraph, second sentence - Add a ")" after the words "0 to 4 kg/g sediment"	added

Conrad	29	Under section 4.1.6 Flow, first paragraph, second sentence - Erin Hestir's dissertation includes an analysis of maximum water velocity thresholds for SAV establishment in the Delta (I have a copy if you would like to review): 1. Hestir EL (2010) Trends in estuarine water quality and submerged aquatic vegetation invasion [Dissertation]. Davis: University of California, Davis. 146 p.	edited and added citation
Conrad	31	Under section 4.1.8, second paragraph regarding reference to Santos et al. 2011 - An important result from this paper that I don't see highlighted here is that Egeria sustains its biomass in the fall/winter, giving it a head-start in growth in the following spring compared to other species.	yes, had this elsewhere but added it here
Conrad	35	Under section 5. Recommendations, R2 - More detail of the vision here? See major comment in the accompanying Word File (my general comment #4)	Tried to give more detail for this recommendation. Note that I did not receive a Word file with general comments from Louise
Cornwell	N/A	General Comments: Overall, this is a good analysis of control of invasive/native macrophytes in the Bay/Delta. As a biogeochemist, my comments are focused on nutrient-related regulation of plant success and the effects of invasive plants on Bay/Delta nutrient cycling and balances. My lab's recent publication in sediment biogeochemistry may be of some help, I didn't emphasize macrophyte effects because we also saw large effects of benthic microalgae in areas with submersed vegetation.	Cited Cornwell paper mentioned here and discussed in multiple places in revised paper
Cornwell	N/A	Specific Comment 1. The biogeochemical feedback of increased plant biomass on water quality, especially low dissolved oxygen and higher nutrient remineralization/release is of concern. Often, as in the Hydrilla invasion of the Potomac River, the results can be beneficial for nutrient balances. I think the concern of poor sediment quality, i.e. high rates of respiration/nutrient release/poor habitat for benthos, is perhaps less of a worry. Our sediment flux work (Cornwell et al. 2014) in several locations with (albeit sparse) submersed aquatic vegetation (Sherman Lake, Big Break, Franks Tract) did not suggest extremely high rates of sediment respiration or nitrogen release, although rates tended to be higher than in non-vegetated Suisun Bay environments. The macrotidal nature of much of this estuary might lead to export of decaying macrophyte biomass "downstream", with only a very modest effect on nutrient balances in the plant bed. However, these concerns are easily tested.	Cited this paper and indicated that a sediment pool of decomposing macrophytes probably only contributes to nutrient balaneces in quiescent areas

Cornwell	N/A	Specific Comment 2. Evaluating the role of nutrients in the spread of invasive macrophytes is a massive challenge. In the Chesapeake, the loss of water clarity from phytoplankton and the proliferation of epiphytes lead to a collapse of grasses; understanding the enhancement of macrophytes by nutrients is more difficult. The hypothesis that enhanced P release from increasing metabolic rates for E. densa is interesting, and in fact we observed high P releases in March 2012 in areas with macrophytes. If plant beds develop conditions conducive to P release over time, with the buildup of organic matter, there may be a strong supply of P, especially from pore water uptake. Thus, there could be a positive feedback.	Agreed, a massive challenge. Cited Cornwell work showing sediment P release in areas with macrophytes
Cornwell	N/A	Specific Comment 3. The absence for routine monitoring of plant biomass, spatial extent, species composition, and relatively standard water quality measures (oxygen, salinity, pH, chlorophyll a, nutrients) in plant beds is the greatest source of uncertainty in the report and an absolute necessity to move forward with modeling and control strategies. This is perhaps the key investment that needs to be made; without this, the extent of the problems will be poorly understood. Any potential investments in more research, modeling, or management suggestions need this basic information.	Yes, beefed up recommendation that a routine monitoring program for the macrophytes should include standard water quality measures
Cornwell	N/A	Specific Comment 4. The suggestion of developing a biogeochemical model of the Delta has been made in this report and from our work, it appears to be a key needed advance. There exist many different models for estuarine ecosystems, and I would suggest that off the shelf models might work well for large scale nutrient cycling and balances. Modeling macrophyte communities remains a huge challenge in estuarine science. The biogeochemical effects of given plant species and biomass are becoming better understood, but models also need to the temporal and spatial patterns of macrophyte abundance.	Yes, emphasized need for information on temporal and spatial patterns in macrophyte abundance needed for modeling efforts
Cornwell	N/A	Overlall Comment and Reference: Overall, this is a useful assessment of the state of knowledge regarding Delta macrophytes, with a number of modest caveats from committee members that were expressed at our meeting. The report includes all plausible environmental controls on biomass, as well as biogeochemical feedbacks. Cornwell, J. C., P. M. Glibert, and M. S. Owens. 2014. Nutrient Fluxes from Sediments in the San Francisco Bay Delta. Estuaries and Coasts	Included citation and discussed its findings in several places

		37:1120-1133.	
Durand	iii	Under Recommendation #4, first bullet on conditions in Delta favoring growth: low turbidity?	added
Durand	iii	Under R1: We need routine nutrient monitoring on a finer scale than we have, too.	yes, added to recommendation
Durand	iv	Under R3: Item 2 in last sentence: Suggestions for control strategies: chemical, mechanical, gated restoration planning, etc.	all now included
Durand	1	Under 1.1: first paragraph, last sentence - Typo on declined [change "declined" to "decline"], wording for "threatened and endangered" to native? desirable?	typo fixed. yes, native used instead
Durand	1	Under 1.1, second paragraph - need an end quote on sentence "…the State Water Resources…".	fixed
Durand	1	Under Potential nutrient related problems, item 1. Decreases in algal abundance - Do you mean phytoplankton?	yes, clarified
Durand	1	Under Potential nutrient related problems, item 3. Increases in the magnitude and frequency of cyanobacterial blooms - Do you mean Microcystis?	wording in the Delta Plan is "cyanobacterial blooms" -- probably means Microcystis
Durand	5	Last paragraph, last sentence - I am certain that it has greatly expanded during the drought.	acreage updated using Shruti's 2014 data
Durand	10	Under section 2.3 third sentence on egeria densa related to growth response under red light - … or conditions with sufficient turbidity to shade out blue light.	revised to say it grows nearer to the surface in turbid water
Durand	12	3rd paragraph on page starting with "egeria densa is thought to have been introduced to the Delta in 1946". - But worth noting that DWR reports from 1993 (Department of Water Resources. 1970-2000. Water Quality Conditions in the Sacramento-San Joaquin Delta. Sacramento, CA.) mention Egeria without alarm; however by 1996 Grimaldo and Hymanson (1999) noted thick stands with lots of alien centrarchids. My point being that some shift in the late century began accelerating the spread of this plant.	Added this
Durand	13	2nd paragraph on Stuckenia sp., first sentence - Louise' (Conrad) comments notwithstanding, this is an interesting way to compare...can you do something like this with Egeria...and how reliable are your estimates?	Can be done with monotypic stands of Stuckenia in Suisun but not in places where Egeria is mixed with other species
Durand	15	Under Chapter 3, first paragraph, second sentence on negative effects - ...usually facilitated by very high densities of alien SAV	yes, clarified

Durand	15	Section 3.1, first paragraph, sentence "In contrast, the open water beneath sparse canopies of native *Stuckenia* sp. may provide …" - I am not sure how well these statements are supported by the literature as well. For example, I am not sure if we have any idea that native fish are particularly associated with Stuckenia. Adverse effects of alien SAV on fishes are more consistent with the literature...but even some of that may have been overstated. For example, while high densities of predators may lurk in SAV patches, there is no evidence to suggest that this is responsible for populations effects of vulnerable native fishes like smelt or salmon.	okay, point taken. Tempered this whole section
Durand	16	Under section 3.1.1, first paragraph, fourth sentence "*E. densa* sheds some biomass in winter but does not fully senesce (Fig. 2.2) - Freezing can make a huge impact. Years (like the last) without a freeze had limited die back. I think Shruti has some documentation or a ref for this.	E. crassipes is greatly affected by freezing. Is this comment referring to E. crassipes or E. densa?
Durand	18	Under section 3.1.4, first paragraph, second sentence on cascading effects - not sure what you mean by this: trophic cascades are typically top down	took "cascading" out
Durand	18	Under section 3.1.4, first paragraph, fourth sentence on thickly growing stems - But it's reasonable to think about this as a management question, because, as we have said, at intermediate densities it probably provides more food access with limited risk. Also, at reasonable densities, it can provide prey refuge, I suspect. the question I have is: how often does it occur at "reasonable densities" and if so, can we find that as an intermediate ideal?	added a sentence on this
Durand	18	Under section 3.1.4, first paragraph, last sentence with effects on the food web - predation effects	added
Durand	19	Under section 3.1.4 under *Eichhornia crassipes* first paragraph, 3rd sentence - I wonder how much this matters to predators? Matt Young at UCD has a lot of insight into this. [Matt's email] mjyoung@ucdavis.edu	have not contacted Matt Young at this point. Toft paper discusses this somewhat and I added more detail from it.
Durand	20	Under section 3.1.5, 2nd paragraph, 1st sentence - [In reference to Conrad's comments on DO] …especially at night.	yes, added
Durand	24	Under section 4.1.1 Light - For what it's worth, my model using Santos' data showed an ambiguous relationship with turbidity, a low probability of establishment at depths below 5 m and a rapidly decreasing probability of establishment with increasing flows.	added this information and cited Durand thesis

Durand	25	Under section 4.1.3 Salinity, first paragraph, second sentence -[In reference to Shruti Khanna's comment] Not sure what you mean Shruti, but the Delta was not necessarily fresher before the 1970's. It had more intra and inter-annual variability than we see now. One of the famous early pieces of evidence for this is the Martinez C&H Sugar plant records which document how far up the Delta they needed to go for freshwater. After project implementation, the Vernalis agreement established a salinity standard, legally prohibiting the intrusion of salinity past a certain point. Clearly, Egeria responds well to the more stable salinity regime. We have recommended salinity variability as a way of controlling a number of alien species. Generally, this has been shot down because of legal implications, in Delta consumptive use and the cost of water.	added more about lowered variability in salinity
Durand	27	Under section 4.1.5, second paragraph, first sentence - But limited at times, in the north Delta, that is, off of the Sac plume.	Not sure what this is referring to; need a reference or more information from JD
Durand	29	Under section 4.1.6 Flow, first paragraph, second sentence - [In reference to Conrad's comments on Hestir's disseration reference] Hestir found a dramatic decrease at .49 ms-1, I found a decrease at around .3 ms-1.	added both values to text
Durand	31	Under section 4.1.8, first paragraph, first sentence - [his comments on the words "is interactions"] case	fixed

Durand	34	Under section 5. Recommendations - Are there really no concrete recommendations that we can bring, at least in the form of hypotheses, about management of the two main invasives? The "more research is needed" is understandable, but not really adequate, given the time and money currently invested in research and management of this beast. I believe we can say a number of things about SAV/FAV distributions, even if we have to qualify the recommendations with a certain amount of uncertainty, or state explicitly that some recommendations remain disputed or controversial. For example, restorations with limited flow and shallow water 1 and 5 meters are going to get a lot of Egeria. Small embayments or eddies on the lee side of channels are going to be heavily impacted by E. crassipes. Regions that can utilize flow pulses of water will be able to "reset". Managed wetlands are able to "reset" by draining. Chemical management is not very effective except for short periods, and is quite spotty in terms of its impact. Mechanical harvesting is slow and the effect is only good for short periods (how long?), but the effect is targeted where it is most needed. The waste can be re-used as fertilizer to subsidize the harvest. Etc, etc. I am sure that at this point, we can describe these and other hypo-recommendations either as targeted research questions or for interim management recommendations....	Information about distributions given. If more information is available that this reviewer wants included, please provide additional comment and citations. Have not given these detailed recommendations but considering whether to do so
Durand	34	Under section 5. Recommendations, first listed item #3 - This may not be your charge, but a fourth question worth considering is how aq. veg will affect restoration and how restoration sites can be managed or designed in anticipation of this.	consider this to be outside scope of this review
Durand	34	Under section 5. Recommendations, second paragraph, second listed item #1 - I said this before, but routine monitoring should include continuous water quality monitoring, flow conditions, and nutrient compositions across the estuary. The SFE is really behind in these basic observational elements.	yes, added this to recommendation

Durand	35	Under section 5. Recommendations, R2 - Also a widely available hydrodynamic model, which will be necessary to understand stand development and dispersal	yes, I think this is covered now
Engle	iii	Under R1: Second senternce on monitoring: We have to be able to quantify the net primary production (changes in biomass over small time periods using tagged whole rosettes or internodes) , expected growth increments based on (standing biomass at "Time A")x(measured NPP), and then compare the expected growth increment to standing biomass at next time point (Time B). This provides NPP and turnover rate. Without those you cant know what the carbon or nutrient flux into and out of the plant biomass is. In other words, standing biomass can be absolutely static even while huge quantities of carbon and nutrients are being fixed in tissue and rapidly turning over.	Agreed, added that ideally primary production would be measured to estimate turnover
Engle	3	Under section 1.2, originally item 6) of the following key questions: What is the relative importance of nutrients and organic matter accumulation … - Not sure that "organic matter accumulation" is meant to be described here as "a factor promoting trends" in the vegetation. At our meeting, it was being discussed as a potential result of vegetation but not the cause of it.	revised accordingly
Engle	5	Last paragraph, first sentence in references (see Literature Cited…) - Rephrase to "Literature Cited, Local and regional press reports"	rephrased
Engle	15	Section 3.1, first paragraph - Floating macrophyte beds also provide a substrate near the water surface for a diverse and large biomass of attached microalgae that can exceed the biomass of phytoplankton in adjacent open water (on a per m2 basis). We may not fully understand how the epiphytic community contributes to production at higher trophic levels. Certainly in my own experience there can be thousands of microcrustaceans and other invertebrates (especially insect larvae) per dry gram of root tissue in floating macrophyte beds. If you would like some references from analogous systems in the Amazon, let me know.	added more on the habitat value of roots and community that develops on it.

Engle	15	Section 3.1, first paragraph, last sentence discussing excessive organic matter accumulation - As we discussed during the meeting, I am not sure if there is accumulation of organic matter in the Delta channels where this stuff grows. I'm sure there is a "rain" of detritus, however - what is the evidence that there is organic sediment build up? It is just as likely that the turnover of biomass yields primarily DOC that is exported downstream. This is the predominant fate of macrophyte-fixed carbon in the Amazon system.	revised to say that it could be a factor where high residence time and minimal export
Engle	16	Under section 3.1.1, first sentence on sediments over time - See my comments above. Are we really getting organic matter build up in Delta sediments? If we are going to emphasize a sediment feedback hypothesis as leading to impairment I would like to see some citations from the Delta confirming that there is organic matter accumulation in the sediments, or this should be couched as hypothesis and a data gap. Also, in a lotic system, nutrients released from sediment into the water column aren't preferentially used by macrophytes...they are available to any primary producer in the downstream environs. In general I find myself wishing for more discussion of fate and transport processes related to elemental stocks in macrophytes since the Delta is a "fluid" system (no pun intended).	greatly reduced this section and discussed likelihood that organic matter fuels nutrient recycling only low flow areas if there is a mechanism of biomass accumulation
Engle	16	Under section 3.1.1, first paragraph, last sentence on page "As aquatic vegetation expands in coverage, this large contribution of organic matter from both natural senescence and management of these abundant plants represents eutrophication. - I really am uncomfortable with this assertion unless we can demonstrate that the macrophyte bed carbon metabolized in adjacent water is causing the Delta waterways to be net heterotrophic.	removed this and reduced whole section it was in
Engle	17	Under section 3.1.2., 1st paragraph, 1st sentence - See my earlier comment regarding macrophyte beds providing a platform for attached microalgae that are maintained near the surface and get plenty of light. In fact, there may be more primary production in attached microalgae being held near the surface than there is in the turbid, mixed water column in adjacent waters.	added this
Engle	19	Section 3.1.5 Changes in Water Quality - Since this paper will be used in a nutrient standard setting purpose, it is important that this section be robust and supported by citations.	increased detail and added citations

Engle	19	Under section 3.1.5 Changes in Water Quality, 1st paragraph, 3rd sentence - The Greenfield citation is about effects of mechanical shredding. Natural senescence is not likely to have the same water quality effects. There ought to be sufficient literature to support a hypothesis about large beds naturally "sinking" - if not, we should leave this out. In my experience, aquatic macrophytes usually lose most of their labile elemental mass while still in the water column as they senesce - which means lots of transport downstream through dissolved organic compounds. You dont usually find hearty masses of decaying stems and other tissues sitting around on the bottom unless there has been a physical disturbance. If massive sinking occur in the Delta in undisturbed beds - it should be backed up with a citation.	point taken. This section heavily edited
Engle	21	Under section 4.1, first paragraph, last sentence - Back in the days when BDCP was generating its conservation measures, they relied heavily on a threshold velocity for Egeria establishment of 0.49 meter per second (m/s) to model the effects of their future operations scenarios on Egeria distribution. This threshold was cited to come from: Hestir, E. L., D. H. Schoellhamer, J. A. Greenberg, T. Morgan-King, and S. L. Ustin. 2010. Interactions between Submerged Vegetation, Turbidity, and Water Movement in a Tidal River Delta. Water Resources Research,(in review) I dont find that this paper ultimately appeared in the literature, but the threshold received lots of publicity in the arena of BDCP-management scenarios and I would like to know if the macrophyte-mavens in the Delta support acknowledgement of this threshold in the white paper. I see further down that this threshold is brought up by other reviewers and came from Hestir's thesis.	incorporated Hestir and Durand findings of thresholds for Egeria establishment. I couldn't find the Hestir paper mentioned so have cited her dissertation
Engle	24	Under section 4.1.2 Temperature - If you take Louise's suggestion about adding water management aspects to the other "factors", you might want to look at the BDCP modeling outcomes for temperature under operations scenarios. They modeled the operations effects on Microcystis (not saying I agree or disagree with their conclusions) by calculating how many days temperature would exceed certain thresholds in the Delta in the future. Cant remember if they published temperature scenarios that include climate change.	Have not reviewed these modeling outcomes at this time

Engle	27	Under section 4.1.3 Salinity, first paragraph, second sentence -Should you let people know you are using PSU, if you are?	Oceanographers I work with insist that salinity has no units and thus psu is not appropriate
Engle	27	Under section 4.1.4, second paragraph - Are there any direct diel measurements of pH inside macrophyte beds in the Delta? If not, this should be acknowledged. I'm skeptical of dissolved-gas mediated changes in water chemistry in lotic settings, although in flooded islands and back sloughs less skeptical.	I have not found direct diel measurements of pH inside macrophyte beds locally. I added a caveat that changes would be greatest in dense beds in quiet waters
Engle	29	Under section 4.1.5, first paragraph on section related to organic loading of sediments - My usual saw...this is highly speculative unless there is evidence that there is continual organic loading of sediments going on in this system (as opposed to rapid export), with subsequent higher release rates of DIN and DIP from sediments where macrophytes are growing.	revised this section to indicate that most organic matter losses are likely to be mostly in dissolved form
Engle	29	Under section 4.1.5, second paragraph on *Eichhornia crassipes* - I dont have time by today to look into Eichhornia dosing experiments, but its seems that there should be more than 1 citation out there regarding Eichhornia dosing experiments. I suspect Shruti may have provided some resources. Given the "charge" to guide the Central Valley Board regarding whether nutrients are driving macrophytes - this nutrient section should be beefed up with a more thorough literature review - and the experimental conditions placed in context of DIN and DIP concentrations from monitoring stations in the Delta to see if any of them are environmentally relevant.	yes, added more citations
Engle	30	Under section 4.1.7 third paragraph, first sentence - Is there a review paper or two to cite, or even the proceedings of some symposia or another?	added citations
Engle	31	Under section 4.1.8, third paragraph, first sentence - It seemed from our meeting that there is concern that the "niche" occupied by Eichhornia would be occupied by SAV if Eichhornia was effectively managed. This "zero sum game" aspect of the Delta macrophyte issue should be discussed more fully in this white paper, in my view.	yes, this shift in composition was already described but it is more explicitly discussed now

Engle	33	Under section 4.2 - There seem to be only a few examples where a hyacinth or SAV-dominated system experienced a state-change to plankton-dominated. In the cases I am aware of, climatic perturbations seem to be a driver, not nutrient management. One case is the state change to low hyacinth in Lake Victoria in the late 1990s. The explanations for this state change have been debated in the literature (bio-control, meteorologic event like an El Nino?). In addition, there was a regime shift from Egeria dominance to turbid open water in the Rio Cruces wetland in Chile that may have been prompted by a climatic event (Marin et al. - citation was among those posted for the group). I think the white paper should have at least a brief section acknowledging cases where some kind of perturbation actually DID result in disappearance of FAV or SAV - it could be instructive for management debate here.	agreed, added that state shifts have been noted for both species
Engle	33	Under section 4.2, third sentence on accumulation of biomass as well as clonal propagation - But at environmentally relevant concentrations for the Delta?	revised as described in previous sections
Engle	34	Under section 5. Recommendations, R1 - Please see my comment about NNP and turnover measurements in the executive summary	revised as suggested
Engle	39	Reference for Marina, V.H. et al. 2009 - spelling is Marin; This paper is not referenced in the paper, but should be regarding regime shifts having to do with climatic perturbations. I wonder if there are other references here that are not cited in the text?	fixed. Citations updated.
Foe	24	You note that light availability is important for successful colonization of Egeria densa, and maximizing its tissue growth and biomass. The Delta has become clearer. The delivery of suspended sediment from the Sacramento River to the Delta has decreased by about half during the period between 1957 and 2001 (Wright and Schoellhamer (2004)[1] and this has resulted in a statistically significant 2 to 6 percent decrease per year in SPM between 1975 and 2005 (Jassby, 2008)[2]. Of course, it is uncertain whether the trend will continue. Might this increase in clarity also increase the biomass and distribution of submerged macrophytes like E. densa? Could this increase in clarity make other factors like nutrients more important? 1 San Francisco Estuary and Watershed Science, 2004 volume 2, issue 2 2 San Francisco Estuary and Watershed Science, 2006 volume 6, issue 1	discussed under sections on light

Foe	24-25	I have observed large rafts of Eichornia crassipes being tidally moved seaward out of the Delta to San Francisco bay in late fall with the first cold snaps. I assumed that colonies lost their cohesive stability under freezing night time conditions. This seems like a potentially significant biomass loss mechanism. Is this true? Is there any mention of this in the literature?	added a decription of effects of cold temps, including this observation
Foe	28	Second paragraph - You say, "High nutrient availability is often cited….." Can you give a reference to support this assertion?	took statement out because hearsay
Foe	29	Redfield ratios are often used in phytoplankton studies to determine which nutrient will become limiting as the nutrient pool is exhausted. Typical phytoplankton N:P Redfield ratios are 7.5:1 (wt:wt) although the number may change somewhat based upon algal growth stage and species. DIN to DIP ratios for Suisun Bay are around 6:1 (Glibert et al 2010). Ratios for the delta are more variable but range between 5 and 10 (Foe et al., 2010). You can get more data from Alex Parker and Dick Dugdale at the Romberg Tiburon Center. N:P ratios are 2 to 3 for Stuckenia sp and E densa in figure 4.4 If so, it seems that macrophytes may have a higher P requirement than phytoplankton and may be more likely to become P limited in the Delta if consuming mostly waterborne nutrients. Can you comment?	added N:P of water thought to be limiting for E crassipes, but otherwise this is still a gap
Foe	29	It would be nice to include a summary table of the key factors controlling macrophytes in the Delta. Left column would be a list of primary macrophyte species and across the top the primary drivers. These might be light, temperature, salinity, DIC, and nutrients. In the cells give the ranges that restrict plant establishment and growth.	I have not done this and most of these numbers could only be very rough with little local data on how the factors work specifically in the Delta.
Foe	34	I think the recommendations are fine but are too general. I suspect that both the monitoring and modelling should be accompanied by special studies to help interpret and inform the results. Maybe under monitoring you could list specific high priority questions in bullet form. For example: Do N and P concentrations limit E. crassipes growth and biomass anywhere in the Delta now? To determine this conduct amendment experiments in the laboratory and/or in field mesocosms to determine growth as a function of nutrient concentrations and compare these with levels found in and around macrophyte beds in the Delta now. What is the limiting nutrient? Are these conclusions robust under different light and temperature regimes typical of	expanded the recommendations to be more detailed, but not as detailed as suggested here

		the delta?	
Foe	N/A	I think the nutrient discussion would be improved by including a paragraph or two on ambient nutrient concentrations and trends over time in the Delta. Annual average DIP and DIN concentrations at key locations in the Delta range between 0.02-0.09 mg/l and 0.13-1.10 mg/l (Foe et al., 2010)[1]. Typical DIN and DIP concentrations are 0.5 and 0.05 mg/l, respectively, but talk with dick dugdale from the Romberg Tiburon Center for more information. All the amendment experiments cited in the review paper are at higher concentrations than occur in the delta and this may affect the interpretation of the results. The results obtained by You et al. for E. crassipes are particularly interesting and suggest the possibility of nutrient limitation in the delta now. You et al. increased N and P concentrations above 0.6 and 0.05 mg/l and observed a 30% increase in growth and clonal propagation. If these findings are confirmed by additional experiments, then nutrient management might be an option for reduce the severity of the water hyacinth problem. Please comment. [1] http://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/ambient_ammonia_concentrations/foe_nutrient_conc_bio_effects.pdf	added several figures on nutrient concentrations in the Delta including ones from Glibert and from Foe. Would like to add a figure like what is in the cyano report if I can get those data. Added more on nutrient limitation and that E. crassipes is unlikely to be limited under current conditions.
Foe	N/A	About trends, nutrient concentrations, N speciation, and dissolved N:P ratios have changed in the delta over the last 40 years. More DIN, more NH4, less SRP and an increase in the N:P ratio (Jassby 2008; Glibert, 20102 ; Van Nieuwenhuyse, 20073). Could these changes in concentrations be partially responsible for the emerging macrophyte problem? [2] Reviews in fishery Science, 18:211-232 [3] Canadian journal of fisheries and aquatic science 64:1529-1542	Although there has been an increase in NH_4^- and a decrease in the N:P ratio over a 30 year period through 2006, especially in the upper Sacramento River, this trend was not evident in the last decade of that time period (Glibert 2010; Fig. 4.5). A closer look at the last decade (through 2013) shows no trends in any form of inorganic nutrients or N:P ratios in the central Delta region -- this comes from the more recent data shown in the Cyano white paper, which I am trying to get.
Foe	N/A	The modelers are going to need specific data to be collected to help inform model development. This paper should note and recommend that there be collaboration between the monitoring and modeling team to collect high priority information to inform the models.	yes noted this

Joab	1	Under 1.1 - In sentence "…critical habitat or fish.." Change "or" to "for".	fixed
Joab	1	Under section 1.1, last paragraph - The Water Board only commissioned two not three literature reviews.	fixed
Joab	3	Under section 1.2, listing for Section 3: Insert "to" between "Contributing" and "the" and capitalize the words "submersed", "floating", "aquatic", and "vegetation" to be consistent in formating.	fixed
Joab	4	Under section 2.2, first sentence - Only 17 species are identified in Table 2.1, not eighteen. Please correct text or Table 2.1.	19 now with addition of 2 by Shruti
Joab	17	Under section 3.1.1., last sentence - "identified" spelled incorrectly.	
Joab	All	Global Comment: I found numerous references cited in document that were not included in the Chapter 6 Literature Cited. Please compare all references in text and Chapter 6.	fixed
Khanna	iv	Under R3: Item 2 in last sentence: adding information to Durand's comments on control strategies: also biological	added
Khanna	1	Under 1.1 - In sentence, "...45,000 square mile" change "mile" to "miles."	fixed
Khanna	1	Under 1.1, second paragraph - the sentence "Studies needed for development of Delta…" seems incomplete - difficult to understand.	need to pull up the language used in this document to fill this in and make more clear
Khanna	2	Figure 1.1 - Maybe pick a different figure? I can't read any of the text in this figure.	can the water board suggest another figure that would be more clear?
Khanna	4	Heading of section 2.1 - "Classification" is misspelled.	fixed
Khanna	4	Under section 2.2, second paragraph reference to Hestir et al. 2010 - As I remember, this figure actually comes from some other paper that Erin might have cited in her paper. I know she did not herself harvest biomass and determine the % coming from Egeria. Moreover, this original paper is even older. I think the timeline is important. I think when you mention cover, biomass ratios, any information pertaining specifically to the Delta, it is better to mention which year this study comes from. Because the Delta is so dynamic and what was true 10 years ago, might no longer be true. Same goes for the Santos et al. 2009 study.	revised this. Tried to always indicate year that data came from.
Khanna	4	Under section 2.2, last paragraph, first sentence on Coontail being the most frequently encountered native species - In 2014, (coontail) found in 45% of all sampled SAV points. Average cover where sampled - 30%.	added
Khanna	4	Under section 2.2, last paragraph, last sentence - What is the citation for these numbers (284 hectares)?	Santos et al. 2011. cited it again.

Khanna	5	Table 2.1 - There are two more species we have documented which I don't see mentioned here - one is water purslane (which is similar to water primrose and floating - genus Ludwigia), the other is parrotfeather (genus myriophyllum), which is actually a floating species.	added to table
Khanna	5	General comment on figures - for new figures, see total area of floating in the excel sheet I forwarded and divide by half to get appx. water hyacinth area. Other half is water primrose.	included these new estimates from the excel sheet from Shruti throughout
Khanna	10	Under section 2.3, last sentence on egeria densa on range of depths in turbid and clear water - but maybe to a shallower depth in turbid water.	added
Khanna	11	Under section on Stuckenia sp. - 2014 survey: Sago or fineleaf found in 26% of sampled points. Avergae cover where samples: 50%. Especially in the open bay. It is found as 100% cover so it looks like it's niche is at least partially unique from all other submerged species.	added
Khanna	11	Figure 2.5 caption - I agree with Louise's comment. We have not been able to differentiate between SAV species even with hyperspectral data. I'd like to see this reference.	see my clarifications on this, and response to Louise's comment
Khanna	12	Thirrd paragraph,fourth sentence "*Egeria* coverage expanded during the years between 2003 and 2007" - I haven't read Maria's paper recently but according to the numbers I have (see the xls file), Egeria was abundant until 2006 then decreased quite a bit in 2007 and even more in 2008.	revised to reflect numbers in Shruti's spreadsheet
Khanna	12	Fourth paragraph, second sentence on Eichhornia crassipes, reference to Santos et al 2009 study - Maria's study was hazy about the efficacy of water hyacinth control. My study found that control had no impact on year-to-year cover of water hyacinth. The decline of cover in 2007 was mainly due to a 3 week period of continuous frost nights in Jan 2007. There are several studies that back up the claim that water hyacinth is vulnerable to frost.	added reference to Khanna study on lack of year-to-year change from control efforts. Added references on frost.
Khanna	12	Fourth paragraph, second sentence on Eichhornia crassipes with mention on estimates of acreage - Take estimates from the SOTER report or the xls file. I have a comment on this earlier.	done
Khanna	15	Section 3.1, first paragraph, highlighted sentences from "In contrast, dense canopies..." to "...leading to predation on smaller adult and juvenile native fish" - [Following Louise Conrad's statement] Moreover, doesn't each of these statements require a citation?	greatly revised this section to address concerns of Louise and John D

Khanna	16	Under section 3.1.1, first paragraph, 4th sentence "*E. densa* sheds some biomass in winter but does not fully senesce (Fig. 2.2) - [In reference to John Durand's comment that Shruti may have references.] Yes, check the annotated bibliographies. There are examples from Florida and Louisiana.	added references
Khanna	17	Under section 3.1.3, fourth sentence "Dense submersed vegetation is ..." - There are a couple of new Hestir et al. papers on the relationship between SAV and turbidity e.g.Hestir, E. L., D. H. Schoellhamer, T. Morgan-King, and S. L. Ustin. 2013. A step decrease in sediment concentration in a highly modified tidal river delta following the 1983 El Niño floods. Marine Geology 345:304-313.	added reference
Khanna	19	Under section 3.1.5 Changes in Water Quality, first paragraph, second sentence - [In reference to Conrad's comments on citations for this section] Yes, many. Kathy, check out the bibliography. If not there, then the Gopal book should have a ton. I think he has a chapter on the use of water hyacinth as a secondary water pollutants purifier.	added references
Khanna	20	Under section 3.1.5, second paragraph, first sentence - [In reference to Conrad's comments on DO] I also seem to remember that Egeria mats can depress oxygen levels.	yes, added
Khanna	20	Under section 3.1.5, second paragraph, third sentence on decomposition of E. crassipes following senescence - Even in a healthy mat, the growth rate of hyacinth is so obscene that there is material constantly dripping from the root system and a thick mat can cause part of its own mat to senesce due to intra-species competition.	agreed, added
Khanna	24	Under section 4.1.1 Light, second paragraph, last two sentences - [In reference to Conrad's comments on these statements] I agree. I think the Stuckenia comment can still stand but maybe instead of Egeria, you can say SAV mats? Especially since Elodea, a native that has increased in the Delta over the past six years, also forms dense canopies identical to Egeria. Also Hestir et al. paper cited in a previous comment.	yes, changed to SAV mats. Added Hestir citation
Khanna	24	Under section 4.1.2 Temperature - For water hyacinth, lower air temperatures can be pretty limiting and this is insufficiently discussed here. I have some references on the subject in the bibliography.	added info and refs on cold temps/frost

Khanna	25	Under section 4.1.3 Salinity, first paragraph, second sentence -This is a matter of debate. The historic delta used to be a lot more of freshwater and the X2 line was much farther away. Only in times of drought would part of the Delta become brackish. And the reason was that the water had a much longer route to take through meandering narrow channels and did not meet with the bay waters as readily. By dredging the Sacramento river and getting most of the water out quickly into the bay, we have reduced the residence time of the water in the Delta thereby ironically increasing the salt intrusion. The thing different in the part was the strong seasonal variability in the salinity - especially more salinity during low-flow. Now the delta is fresh all year long. This is the crucial change. References?? I have a bibliography on the Delta too, I think. I'll send it to you directly.	Durand had conflicting view. Added info about salinity variability being decreased.
Khanna	27	Under section 4.1.3 Salinity, second paragraph - there are many salinity studies for eichhornia and they are all mentioned in my annotated bibliography. Please take a look.	added more citations
Khanna	27	Under 4.1.3 Salinity, second paragraph - [In reference to Conrad's comment on this section] probably field data?	yes, field data but weak so added citations from other regions
Khanna	28	Under section 4.1.5, second paragraph - There are many studies of Eichhornia with nutrients but in a slightly different set of literature - paper on water purification plants. I'm not sure if I have much in my bibliography but if you research use of water hyacinth in water purification, you'll get some good references.	added more citations
Llaban	ii	Under Major Finding #1, first sentence - Native floating aquatic vegetation (i.e. pennywort) can also be a beneficial component (invertebrate habitat and trophic support). Toft et al 2003 found higher insect densities in pennywort vs. hyacinth and that invertebrates associated with pennywort occured more often in diets of adjacent fish.	yes, added native floating to sentence indicating it is typically beneficial. Toft reference cited in another section to help capture the comment
Llaban	iv	Under R3 - Mechanical removal/harvesting of water hyacinth is already being implemented by DBW in the Delta as a part of an integrated pest management program (Water Hyacinth Control Program).	added this
Llaban	1	Under 1.1, first paragraph, last sentence on Delta Plan - Please include a full reference under literature cited.	need to add
Llaban	3	Under section 1.2 regarding key questions 4-7 - Should these questions be numbered starting from 1?	fixed

Llaban	11	Under Eichhornia crassipes paragraph, first sentence on windy periods- High tides can also cause water hyacinth to dislodge from shores or tule islands and move with the tidal flux. Disturbance from boating activity can also cause water hyacinth to detach and float around. (DBW staff observations)	added
Llaban	11	Under Eichhornia crassipes, paragraph, second sentence regarding abundance - Also has been historically abundant near USBR's Tracy Fish Collection Facility and River's End Marina (Old River) due to hydrodynamics and waterway characteristics. Related news articles at http://www.recordnet.com/article/20121222/A_NEWS/212220315 http://www.contracostatimes.com/contra-costa-times/ci_24673609/state-begins-using-mechanical-harvesters-control-water-hyacinth	added these locations
Llaban	11	Under Eichhornia crassipes paragraph, third sentence regarding channel edges - Also can be found around tule islands in the middle of a channel.	added
Llaban	12	Under Egeria densa paragraph concerning active management spraying - Suggest avoiding the word "spraying" and rephrase to "herbicide application" or "herbicide treatment". Egeria densa treatments are done with application of granular (pellet) formulations of herbicide, rather than spraying of liquid herbicide. In the rest of the paragraph change "spraying/sprayed" to "treatment".	done
Llaban	12	Under Eichhornia crassipes paragraph, second to last sentence regarding "spraying over several years" - Please change the word "several" to "two". 2011 and 2012 were years where there were delays in permitting between DBW and federal agencies.	done
Llaban	15	Under section 3.1, first paragraph, third sentence regarding shading of phytoplankton - Can also decrease dissolved oxygen in water (as depicted in Figure 3.1).	added discussion of DO effects
Llaban	18	Under section 3.1.3, first paragraph, last sentence on west Delta - Also observed by DBW staff in east Delta.	added pers. comm.
Llaban	20	Under section 3.16, third sentence referencing "boating" - In return, boating activity can facilitate spread of egeria densa by production of plant fragments from propeller disturbance.	added
Llaban	24	Under section 4.1.1, third paragraph, last sentence on E. densa expanding more rapidly - Under what conditions? Low light?	yes, fixed

Llaban	27	Under second paragraph, first sentence regarding local studies - Found a report from a UC Berkeley student on salinity effects on water hyacinth. http://nature.berkeley.edu/classes/es196/projects/2004final/Cheng.pdf This is not a peer-reviewed article and appears to be a class project, so I'm unsure if it can be used as a reference.	have not reviewed this report yet to determine appropriateness
Llaban	30	Under section 4.1.7, first paragraph, last sentence - This section should include a description of benthic barriers as an alternative control measure (cultural control) to control small infestations of Egeria densa in or around high-use areas such as docks, boat launches and swimming areas. I'm not aware of use of benthic barriers in the Delta, but it has been used in Emerald Bay to control Eurasian watermilfoil.	added. Still need to search for info from other locations like Emerald Bay.
Llaban	30	Under section 4.1.7, second paragraph, first sentence on mechanical removal - In general, there are concern about impacts to non-target plant species and by catch of non target organisms, that should be addressed in this section. A useful reference: Biology and Control of Aquatic Plants. A Best Management Practices Handbook.	added. Have not been able to get this book.
Llaban	30	Under section 4.1.7, second paragraph, last sentence on concerns - Another concern is potential survival and regrowth of cut water hyacinth. Reference: Spencer et al 2006. Evaluation of Waterhyacinth Survival and Growth in the Sacramento Delta, California, Following Cutting. Journal of Aquatic Plant Management 44:50-60.	added to text and cited
Llaban	30	Under section 4.1.7, third paragraph, fifth sentence regarding no biological control methods - USACE released Neochetina bruchi in the Delta in the early 1980s. USDA-ARS also has done some releases of Neochetina.	updated this whole section on biological control
Llaban	32	Figure 4.6 - Left figure is cutoff. Please resize to present the complete 2007-2008 data.	fixed

Llaban	33	Under section 4.1.9, first paragraph, last sentence - Vegetative growth is not limited by depth and bank slope. However, water hyacinth seed germination and seedling establishment can be limited by depth and requires shallow water. Although vegetative reproduction is likely the primary means of reproduction, factors affecting sexual reproduction should be considered. Barret 1980 conducted a study of seed production germination in the Delta near Stockton, Ca. S.C.H. Barrett. 1980. Sexual Reproduction in Eichhornia Crassipes. II. Seed Production in Natural Populations. Journal of Applied Ecology. 17:113-124.	Added and cited.
Llaban	34	Under section 5 Recommendations - Section title is inconsistent with title on pg. 3 - "Section 5: Key Data Gaps and Research Recommendations". Please revise either title for consistency.	fixed
Llaban	36	Under section 6 Literature Cited - Many references within the body of the paper are missing from the literature cited section. Please revise the literature cited to ensure consistency with referenced literature.	done
Madsen	5	Recommendation 1. Aerial remote sensing, whether by satellite or aircraft, provide useful data on water hyacinth distributions, but perform extremely poorly on egeria or any other submersed plant communities. Species discrimination with remote sensing is still insufficient to categorize species composition without significant ground truthing. The recommendation does not indicate how biomass estimates would be derived from transects, nor does what technique is planned for transect.	clarified throughout document. Added more detail on biomass estimates
Madsen	5	Recommendation 2. The authors are assuming that nutrients are limiting plant growth without knowing if this, in fact, is the case. It is doubtful that an ecosystem model will indicate if nutrients are limiting either water hyacinth or egeria. It is far more common to see luxury consumption of nutrients by submersed and floating aquatic plants than nutrient limitation.	Need help from SWG to decide how to address

Madsen	6	Recommendation 3. Why do the authors want to reinvent the wheel on management of invasive species? Why select a management technique that is already known to kill fish – namely, harvesting? USDA ARS has already been doing this research for decades, as has the US Army Engineer Research and Development Center. This recommendation is made, yet no citations of existing best management practices manuals are included in this report. The Journal of Aquatic Plant Management has 2,000 articles on the biology and management of aquatic macrophytes, and has ONE citation in the report. The San Francisco Estuary Institute had a multi-year project to investigate harvesting to replace herbicides for management in the early part of the last decade, and concluded that harvesting was not a replacement for herbicides.	changed this recommendation to suggest a revew of existing and planned mthoeds of control with an eye to effectiveness in meeting nutrient objectives and increasing beneficial uses
Madsen	17	Rake methods. Rake methods to "estimate biomass" are poor substitutes for actually measuring biomass.	true, but this is the method that has been done
Madsen	19	Coontail does not "attach to other plants." It might wrap around other plants. It lies on the surface of the sediment.	fixed
Madsen	22-23	Egeria densa. I realize that, in trying to be understood by non-scientists, many people use the term "male" and "female" plant or flower, but the plant or flower itself is not male or female. The plant or flower is correctly referred to as either "staminate" or "pistillate," not male or female.	yes, corrected
Madsen	23	Water hyacinth. While water hyacinth does produce a large number of seeds, outside of their native range they have very low germination rates, and the seedlings take exceedingly long to grow. A seedling may not be capable of producing a flower until the end of the year. For overwintering, the importance of the stembase cannot be overstated. The stembase can lie underwater during the cold season, and initiate growth rapidly in the new growing season.	added both these points
Madsen	23	Coontail does not attach to other plants. It is neither epiphytic nor saprophytic.	fixed
Madsen	26	Line 5. M. spicatum is misspelled as spicatam. Repeatedly.	fixed (2 locations)
Madsen	26	Line 23. Submersed herbicide application is inaccurately described as "spraying," when in fact liquid herbicides for submersed plants are injected beneath the water's surface using trailing weighted hoses. Since most of the fluridone in the past decade has been applied as a granular formulation, "spraying" is even more inaccurate.	fixed

Madsen	27	Stuckenia distribution. Unless remote sensing is ground truthed, it is not a reliable method for estimating the distribution of submersed plants. More than half of the population will be out of detection, and the amount remaining undetected will vary based on water clarity and other issues.	Stuckenia is well predicted within Suisun Bay where it is nearly monotypic; in Delta this is only true in open water areas according to Shruti
Madsen	N/A	Global Comment. By the way, most of the figures did not download from Google Documents.	True, hopefully he was able to look at original version sent out
Madsen	N/A	Global Comment. About half of the Literature Cited citations are incomplete, making it impossible for me to look up these citations.	fixed
Moran	i	Acknowledgments: Does the author mean this Macrophyte Science Working Group? Or is there a separate Submersed and Floating Macrophyte Technical Advisory Group?	There is a Science Working Group and also a Stakeholder and Technical Advisory Group. This was clarifed.
Moran	ii	Executive Summary: Text indicates four major questions, but only three are listed.	fixed
Moran	ii	Executive Summary: Major Finding #2, aquatic weed coverage values are too low -CDBW-CA Parks estimates *Egeria densa*coverage at 10,000-15,000 acres or 4,050-6,075 ha. -Water hyancinth coverage in the Delta is much more than 200 ha. In 2014, for example, the Division of Boating and Waterways-CA Parks treated 2,617 acres or 1,060 ha. In 2015, they plan to treat close to 3,400 acres or 1,377 ha. DBW estimates at least 5,000 acres or 2,025 ha in the Delta. See comments from Ustin lab for more precise estimates of coverage. Provide information on increase in coverage from mid-2000s to now. [See reference below.]	Updated with Shruti's numbers in excel sheet
Moran	ii	Ustin lan, UC Davis, estimates 2000 ha, 1/2 Water hyacinth, 1/2 Ludwigia -This study should consider other important aquatic invasive macrophytes for which there is currently no control program, especially Ludwigia spp., which is likely as widespread or more widespread than water hyacinth and equally damaging (and the two weeds co-occur and appear to benefit from each other's presence)	Ludwigia now addressed. Pointed out as a finding that there are additional problematic invasive species that have not received much attention.
Moran	iii	Recommendation R1: (Comment for discussion) Remote sensing data for water hyacinth are being collected by NASA as part of the USDA-ARS Areawide Project for improved control of aquatic weeds in the Delta. R1: Check spelling of "areal" (correct is "arial")	areal was intended -- it means across an area
Moran	iii-iv	Recommendation R2: This should be communicated to the Modeling Work Group. The Macrophyte work Group could identify data requirements.	yes, added this in recommendation

Moran	iv	Recommendation R3: The USDA-ARS Areawide Delta Aquatic Weed Management Project is conducting pilot studies on integrated control.	added that current and planned control methods should be evaluated relative to nutrient objectives
Moran	3	Under Introduction Section 1.2 Goal and Organization of Macrophyte Literature Review - Key Questions: Why are they numbered 4,5,6, and 7?	some kind of auto-formatting--fixed
Moran	5	Information on coverage of water hyacinth, see above and information from Ustin lab on correct coverage estimates.	used estimates provided by Shruti
Moran	10	Under Chapter 2 General Ecology and Trends, Section 2.3 Habitat Types in which they are typically found - *Egeria densa* some of the information here is redundant with page 8.	fixed
Moran	12	Under Chapter 2 General Ecology and Trends, Section 2.4 Spatial and Temporal Trends in Distribution and Abundance - DBW-CA Parks is treating up to 4-5% of Delta area for Egeria densa.	added this percentage
Moran	13-14	Under Chapter 2 General Ecology and Trends, Section 2.4 Spatial and Temporal Trends in Distribution and Abundance - Are there specific causes of the Stuckenia expansion over the past 20+ years? Describe here or in Section 4.	added text that it could be increased water clarity but that we don't know
Moran	16	Under Chapter 3 Role of Submersed and Floating Aquatic Vegetation in Supporting Delta Ecosystem Services 3.1.1 Organic matter subsidy/accumulation - For more information on seasonal growth and senescence of water hyacinth, see also Spencer, D. 2005. Seasonal growth of water hyacinth in the Sacramento/San Joaquin Delta, California. J. Aquat Plant Manage. 43:91-94.	Added this citation
Moran	17	Under Chapter 3 Role of Submersed and Floating Aquatic Vegetation in Supporting Delta Ecosystem Services 3.1.3 Habitat alteration - Can Egeria densa alter habitat in ways that helps it outcompete Stuckenia and other submersed natives? Refer reader to Section 4.1.8	referred to chapter 4 here
Moran	17	Under Chapter 3 Role of Submersed and Floating Aquatic Vegetation in Supporting Delta Ecosystem Services 3.1.3 Habitat alteration - Water hyacinth and Ludwigia often grow together, although one dominates. Could mention here and refer to Section 4.1.8.	about half each in 2014 -- already mentioned
Moran	18	Under Chapter 3 Role of Submersed and Floating Aquatic Vegetation in Supporting Delta Ecosystem Services 3.1.4 Trophic support - Redundant information in the paragraph about Egeria densa providing hiding habitat for predatory non-native fish.	fixed

Moran	19	Under Chapter 3 Role of Submersed and Floating Aquatic Vegetation in Supporting Delta Ecosystem Services 3.1.5 Changes in water quality - Consider more references here and in the more detailed nutrient section later on to support statement of use of water hyacinth to remove nutrients from sewage or other nutrient-rich water. Reddy, K. R., M. Agami and J. C. Tucker. 1989. Influence of nitrogen supply rates on growth and nutrient storage by waterhyacinth (Eichhornia crassipes) plants. Aquat. Bot. 36:33-43. Reddy, K. R., M. Agami and J. C. Tucker. 1990. Influence of phosphorous on growth and nutrient storage by water hyacinth (Eichhornia crassipes Mart. Solms.) plants. Aquat. Bot. 37:355-265. Moran, P. J. 2006. Water nutrients, plant nutrients, and indicators of biological control on waterhyacinth at Texas field sites. J. Aquat. Plant Mgmt. 44:109-115. 2006. (This paper, based on Texas field sites, supports earlier work by other authors in tanks showing a positive association between dissolved inorganic N in water and % N content in water hyacinth leaves, although in this study no associations were found between soluble water P and plant % P, in contrast to a number of other studies. This study did not examine plant growth; however no associations were found between water N or P and plant size)	added citations here and in Chapter 4
Moran	20	Under Chapter 3 Role of Submersed and Floating Aquatic Vegetation in Supporting Delta Ecosystem Services 3.1.5 Changes in water quality - The DBW-CA Parks aquatic weed control programs include DO monitoring requirements and follows thresholds established by the CVRWQCB or other agencies for minimum DO levels under which treatments may be conducted (5-7 ppm)	added this information
Moran	25	Under Chapter 4 Factors Contributing to the Prevalence of Submersed and Floating Aquatic Vegetation in the Delta 4.1.2 Temperature - Not local, but studies have been done to show that above about 33-34 C, water hyacinth loses nutrients from the roots and experiences negative growth.	added pers. comm., need citation

Moran	27	Under Chapter 4 Factors Contributing to the Prevalence of Submersed and Floating Aquatic Vegetation in the Delta 4.1.2 Temperature - One past review indicates that water hyacinth cannot tolerate salinity above 2 ppt. This may not be accurate in the Delta. Wilson, J. R., Rees, M., Holst, N., Thomas, M. B., Hill, G. 2001. Waterhyacinth population dynamics. pp. 99-103 in Julien MH, Hill M. P., Center T. D., Jianqing, D. (eds.), Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes. Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth, Beijing, China, 9-12 October, 2000. ACIAR, Canberra, Australia.	couldn't get this review
Moran	28	Under Chapter 4 Factors Contributing to the Prevalence of Submersed and Floating Aquatic Vegetation in the Delta 4.1.5 Nutrients - Can you provide information on average and range of N and P values in the Delta, and compare to averages for other key estuaries such as Chesapeake? What do you mean by "high" nutrient levels?	added info on average and range of N and P values in the Delta. Added reference to impairment indices. Did not compare to other estuaries such as Chesapeake because absolute values of nutrient concentrations not useful unless there is info on water clarity, phytoplankton blooms, filter feeding ,etc.... which is beyond what we want to get into here
Moran	29	Under Chapter 4 Factors Contributing to the Prevalence of Submersed and Floating Aquatic Vegetation in the Delta 4.1.5 Nutrients - The conclusion that E. densa management cannot likely be improved much using nutrient management is important and should be restated at the end.	done

Moran	30	Under Chapter 4 Factors Contributing to the Prevalence of Submersed and Floating Aquatic Vegetation in the Delta 4.1.7 Chemical, mechanical, and biological control - Major errors in fact regarding biological control -The U.S. Army Corps of Engineers and CDFA released three agents for water hyacinth in the early 1980s in the Delta: Stewart, R. M., A.F. Cofrancesco, and L.G. Bezark. 1988. Biological control of waterhyacinth in the California Delta. U.S. Army Corps of Engineers Waterways Experiment Station, Technical Report A-88-7. U.S Army Corps of Engineers, Washington, D.C.-CDFA conducted surveys in the early 2000s and found that only one agent, the weevil Neochetina bruchi, is established in the Delta. It is widespread but is not having sufficient impact. A key reason appears to be the inability of immature stages to survive winter conditions in the Delta. Akers, R. P., and M. J. Pitcairn. 2006. Biological control of water hyacinth in the Sacramento-San Joaquin Delta year 3 - final report. California Department of Food and Agriculture, Sacramento, California, USA.	added this info and citations
Moran	30	Section 4.1.7 Chemical, mechanical and biological control - Major errors in fact regarding biological control **<u>Continued comment from above:</u>** -Plant nutrient levels in water hyacinth in the Delta are likely sufficient for Neochetina weevil development: Spencer, D. F., and G. S. Ksander. 2004. Do tissue carbon and nitrogen limit population growth of weevils introduced to control waterhyacinth at a site in Sacramento-San Joaquin Delta, California? Journal of Aquatic Plant Management 42:45-48. CDFA and the USDA-ARS are beginning to release a planthopper, Megamelus scutellaris, for biocontrol of water hyacinth. This insect was discovered and characterized as being sufficiently host-specific to water hyacinth by the USDA-ARS in Florida, where it is now widely established, with impact evaluations ongoing. Tipping, P. W., A. Sosa, E. N. Pokorny, J. Foley, D. C. Schmitz, J. S. Lane, L. Rodgers, L. McCloud, P. Livingston, M. S. Cole, and G. Nichols. 2014b. Release and establishment of	added this info and citation

		Megamelus scutellaris (Hemiptera: Delphacidae) on waterhyacinth in Florida. Florida Entomologist 97:804-806.	
Moran	30	Section 4.1.7 Chemical, mechanical and biological control - Major errors in fact regarding biological control **Continued comment from above:** (and Patrick Moran, USDA-ARS Exotic and Invasive Weeds Research Unit, Albany, CA, pers. comm.) -No biocontrol agents have been released for any of the other non-native weeds listed. -Biocontrol using non-native natural enemies is not be an option for control of native aquatic plants that may sometimes be invasive/cause problems, such as coontail and pennywort. Biocontrol using native natural enemies that are reared and released in large numbers (such as a native fungus or a plant-feeding insect) may be an option.	added this info
Moran	30	Gopal 1987 book cited here is not listed in Literature Cited.	fixed
Moran	30	The conclusion that biocontrol poses a unique risk to DO is flawed. Biocontrol of water hyacinth reduces the size of plants over several generations of growth: Tipping, P. W., M. R. Martin, E. N. Pokorny, K. R. Nimmo, D. L. Fitzgerald, F. A. Dray, Jr., and T. D. Center. 2014a. Current levels of suppression of waterhyacinth in Florida, USA. Biological Control 71:65-69. Biocontrol does not cause rapid sinkage that would be associated with DO declines. Also, biomass accumulation in sediments in areas of water hyacinth invasion will occur in either the presence or absence of biocontrol, in areas of low flow; biocontrol will reduce the problems caused by living plants. In any event, biocontrol would not pose any greater DO hazard than herbicidal control, and in fact would pose less of a hazard.	revised text and added citation.
Moran	32	Under Chapter 4 Factors Contributing to the Prevalence of Submersed and Floating Aquatic Vegetation in the Delta 4.1.8 Interactions with submersed or other floating species - Fig 4.6 (Left, Bar charts). I assume that Ludwigia is the pink bars after yellow, but this is missing in legend. The figure is partially cut off on the right.	figure placement fixed. Color coding is identified in the caption

Moran	34-35	Under R1, include monitoring of water and plant nutrient content and analysis of their relationships. Also water flow. Possibly also rates of growth.	added
Moran	34-35	R3 is already underway through the USDA-ARS Areawide Project focused on water hyacinth and Egeria densa.	mentioned this
Moran		General Comment on the evaluation factor - All of the major water quality problems caused by the proliferation of water hyacinth and Brazilian waterweed in the Delta have been identified. "**Yes"**	good
Moran		General Comment on the evaluation factor - All physical and biological factors that influence the abundance and distribution of these invasive aquatic weeds have been identified. **"YES, but little quantitative information is provided on the environmental tolerances of the aquatic weeds in terms of salinity, water flow, turbidity, may be other factors such as temperatures. Information could be provided on what is known for the Delta (lots of gaps), and what is known from other areas.**	these topics more extensively reviewed now
Moran		General Comment on the evaluation factor - Evidence is presented that ambient nutrient concentrations influence or do not influence the growth, distribution and abundance of aquatic weeds. **More quantitative information is needed on typical nutrient levels in the Delta, and nutrient requirements/concentration ranges in the aquatic weeds, and effects on plant growth (not well-studied in the Delta, so would be mostly from other regions).**	quite a bit added on this
Moran		General Comment on the evaluation factor - The White Paper findings are fully supported by the literature and there is no additional unreferenced information that either supports or refutes the findings. **Additional references have been suggested.**	Added many more citations
Moran		General Comment on the evaluation factor - The prioritized list of nutrient recommendations include all questions that need to be resolved before it can be concluded that nutrient management will reduce the severity of the invasive aquatic weed problem in the Delta. **NO, the monitoring plan under R1 needs to include water nutrient, plant nutrient, and plant growth information. Also, studies are needed on nutrient changes resulting from control-killed plants being left in place vs removed.**	Included

Moran		Additional Questions from the STAG: Is nutrient management necessary for management of macrophytes **UNCERTAIN** a. Yes or No? b. If so, what level?	okay
Moran		Additional Questions from the STAG: Is nutrient management alone sufficient to control macrophytes? **UNLIKELY**	okay
Moran		Additional Questions from the STAG: What combinations of management actions (nutrient and non-nutrient) are likely to achieve equal levels of benefit with regard to macrophyte management? What are the likelihoods, costs, and potential unintended consequences of these different strategies?	no comment made
Moran		Additional Questions from the STAG: How do stands of macrophytes affect nutrient dynamics in surrounding waters? **Include under R2**	done
Moran		Additional Questions from the STAG: How do stands of macrophytes affect higher-level organisms, including POD species? **Some studies underway as part of USDA-ARS Areawide Project. Invertebrates in water hyacinth roots before/after chemical herbicide control.**	did not discuss at this point

7.2 Comment Matrix and Responses to Stakeholder and Technical Advisory Group

Author	Comment	Response
Bedore	Specific Comment 1. The White Paper provides a general description of the types of impairments that can be associated with macrophyte over-abundance, but there should be greater detail provided on the actual nature of macrophyte-related impairments in the Delta itself. The impairments should be linked to the Beneficial Uses of the Delta as they are described in the Water Quality Control Plan for the Sacramento and San Joaquin River Basins (2011), and the frequency, magnitude, and geographic extent of macrophyte-related impairments should be described for each Beneficial Use. It should also be determined, to the best degree possible, the level of macrophyte management that is necessary to fully achieve these Beneficial Uses.	Did my best to increase the detail in this. Have not linked them to the Beneficial Uses of the Delta document mentioned. I do not have the information on frequency, magnitude and geographic extent of macrophyte related impairments. I don't think we can determine at this time the level of management needed to acheive beneficial uses.
Bedore	Specific Comment 2. A detailed life history for each macrophyte of interest is also recommended to provide context for describing why various physical and biological factors influence their abundance and distribution. Details particular to the life cycles of macrophytes in the Delta would be most helpful.	Life history info has been added, but probably not to the degree desired here. I need to be careful to not exceed my charge or scope.

Bedore	Specific Comment 3. A more thorough review of all known and relevant efforts related to macrophyte management in estuaries should be provided. From this review it could then be determined under what conditions nutrient management or management of other factors (physical removal, herbicide treatments, hydrological controls, etc.) are likely to be successful, and whether control of those factors is possible and/or likely to be effective for the Delta given its unique hydrology and water quality. This information should then be used to rank the probable efficacy of possible macrophyte management options for the Delta.	Added detailed information about management in the Delta. Added a recommendation to review the current and planned control methods with respect to nutrient objectives.
Bedore	Specific Comment 4. Recommendations to expend resources on nutrient/macrophyte-related research should consider the overall probability that nutrient management, relative to other management options, is likely to provide an effective means for addressing the known macrophyte impairments in the Delta.	added more discussion of the fact that there have been massive increases in problematic species during a period when increased nutrients or changes in ratios has not been observed. Suggests that nutrient management may have limited effects compared to other factors controlling the macrophytes.
Lee	Overall Comment: The findings expressed in the draft white papers are consistent with our many years of experience investigating nutrient-related water quality, our findings in investigating Delta nutrient impacts and control of excessive aquatic plants, as well as with the findings expressed in presentations made at the CWEMF Delta Nutrient Modeling Workhop discussed below.	good to hear
Lee	Basically, the water quality/beneficial use of the Delta is seriously degraded by excessive growths of aquatic plants that are caused by excessive nutrient loads to, and within, the Delta.	We have not been able to make the link that excessive nutrient loads are the leading reason for excessive macrophyte growth, although we have not ruled out that they contribute
Lee	There remains little ability to quantitatively and comparatively describe the role of nutrients (N and P) in controlling the excess fertilization of the Delta waters.	that's right
Lee	There is considerable misinformation in the professional arena on the relative roles of N and P concentrations and loads, and the ratios of N to P in affecting water quality in the Delta; some of the information presented on nutrient/water quality issues is biased toward preconceived positions.	do not know what biases are being referred to
Lee	Based on the results of the US and international OECD eutrophication study and our follow on studies of more than 600 waterbodies worldwide (lakes, reservoirs, estuarine systems) the planktonic chlorophyll levels in the Central Delta are well-below those that would be expected based on the phosphorus loads to the Delta.	yes, this is mentioned in the review

Lee	There is a lack of understanding of the quantitative relationship between nutrient loads and fish production in the Delta.	probably true, not sure what the specific comment is here
Lee	The Delta Stewardship Council's timetable for developing Delta nutrient water quality objectives by January 1, 2016, and to adopt and begin implementation of nutrient objectives, either narrative or numeric as appropriate, in the Delta by January 1, 2018 is unrealistically short.	A comment for Chris to address
Lee	There is need for substantial well-funded, focused, and intelligently guided research on Delta nutrient water quality issues over at least a 10-yr period in order to develop the information needed to generate a technically sound and cost-effective nutrient management strategy for the Delta.	A comment for Chris to address
Lee	As discussed in our writing, some of which are noted below, it wil be especially difficult to develop technically valid and cost-effective nutrient control programs for excessive growths of macriphytes in the Delta.	okay