Mechanisms for the Effective Biological Control of the Invasive Water Hyacinth, *Eichhornia crassipes*, in the Sacramento-San Joaquin River Delta, California

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Services provided by the Delta are severely limited as a result of invasive aquatic weeds, such as the water hyacinth, *Eichhornia crassipes*. In the early-1980s, three biological control agents: a moth, *N. albiguttalis* and two weevils *Neochetina bruchi* and *N. eichhorniae* were released for the control of water hyacinth in the Delta. To date, it appeared that only *N. bruchi* persisted, and current control outcomes have not reached the desirable levels observed in other regions where classical biological control has been implemented. Here, we explore possible mechanisms for inadequate biological control of water hyacinth in the Delta including: 1) insufficient climate matching and temporal declines in the winter, 2) genetic bottlenecks, and 3) a microsporidian pathogen. We conducted monthly surveys from June 2015-2016 across 16 locations in the Delta to determine the spatial and temporal variation of the weevils, examine the genetic variation, and determine microsporidian abundance and distribution in *N. bruchi*. Averaging across months, densities of weevils per destructively sampled plant were 6.83 at one site and 0.31 at another site (26 km away). Averaging across locations, weevil densities ranged from 5.35 to 6.22 in August-November, and low densities ranged from 2.09 to 0.55 in February-June. Through morphological and molecular characterization, using PCR and sequencing the COI region, we discovered that both *N. bruchi* and *N. eichhorniae* have persisted in the Delta, with the majority of weevils identified as *N. bruchi*. Additionally, we confirmed the presence of a microsporidian in *N. bruchi* across the Delta, with seasonal variation in pathogen intensity. We will identify this microsporidian species and continue surveys to determine if this pathogen could be hindering the performance of *N. bruchi*. Lastly, we propose potential solutions to increase the efficacy of biological control of water hyacinth in the Delta.

Keywords: aquatic weeds, biological control, Delta, genetic variation, microsporidia, water hyacinth
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Food Web Impacts of Invasive Aquatic Weed Control in the Sacramento-San Joaquin Delta

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In the Sacramento-San Joaquin Delta and surrounding tributaries, invasive aquatic plants, such as water hyacinth, *Egeria densa*, and spongeplant, degrade physical habitats and change water quality, which negatively impacts the endangered Delta Smelt (*Hypomesus transpacificus*). To help combat this growing problem, the Division of Boating and Waterways has suggested the application of two new herbicides, Penoxsulam and Imazamox, for a more efficacious control over invasive aquatic vegetation. However, potential adverse effects of these herbicides on endangered Delta Smelt, and its prey, *Eurytemora affinis*, has not been extensively researched. This study compared the toxicity of Penoxsulam and Imazamox, as well as the current-use herbicides glyphosate, 2,4-D, and fluridone, to Delta Smelt and *E. affinis* (glyphosate only). Delta Smelt embryos (1-2 days post fertilization) and larvae (1-2 days post hatch) were exposed to chemicals for 96 h with an 80% renewal at 48-hr, then transferred to clean water until hatch (embryo) or up to 4 days (larvae). Endpoints evaluated included embryo hatching success, larval survival, and morphometry. Copepod tests were 96-hr chemical exposure with an 80% renewal at 48-hr and evaluated survival. Results demonstrate that 1) of the two species, *E. affinis* is more sensitive to these herbicides than *H. transpacificus*, as copepod LC50s were generally lower than Delta Smelt; and 2) the current use herbicides elicit more sub-lethal toxic effects on Delta Smelt than Penoxsulam and Imazamox. However, these negative effects were observed at concentrations well above application rates, lending an acceptable margin of safety for use of these herbicides. These findings are relevant to issues occurring within the Bay-Delta, as these results provide food web-level analyses, which will aid managers in choosing the appropriate control measures for combating these invasive aquatic plants while still maintaining the integrity of aquatic fauna within the Bay-Delta ecosystem.

Keywords: Food Web, Delta Smelt, Copepods, Herbicides, Ecology, Invasive Species, Contaminants
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Detecting Invasions and Changes in San Francisco Estuary Sessile Invertebrate Communities over Sixteen Years (2000 to 2015) in Response to Salinity and Temperature Conditions

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Invasions by non-native species are well-known drivers of significant ecological change worldwide. Despite considerable available information on marine invasions in California, and particularly the San Francisco Bay region, it remains challenging to detect new invasions and estimate actual changes in invasion patterns, such as rate and spread. These data are key to understanding invasion processes and informing management and policy aimed at prevention of new invasions and responses to existing invasions. We addressed this issue for hard substrate-dwelling sessile invertebrate communities, which make up a significant portion of invasions worldwide, by conducting repeated, standardized surveys of fouling communities throughout the San Francisco Estuary over a fifteen-year period spanning a wide range of environmental conditions.

We characterized communities using settlement panel surveys at sites throughout the estuary, from Antioch to the Golden Gate to the Dumbarton railroad bridge in the South Bay, from 2000 to 2015. These years spanned recent dry and wet extremes, including major droughts and wetter winters.

Non-native species were prevalent throughout the estuary, but achieved greater dominance following dry winters. Community composition at any given site during the summer period (May to October) was predicted by temperatures during community development as well as the previous winter's salinity levels. Rarefaction analyses and richness estimators indicate that the number of species detected varied both as a function of the number of sites sampled in a given year and with environmental conditions, indicating that standardized sampling across a broad range of conditions over time is required to capture invasions. For years when at least ten sites were sampled, an asymptote in estimated richness was reached, indicating statistically sufficient sampling to estimate the true richness of the community. This large dataset allows us to better understand the influence of physical characteristics on invasion patterns in the San Francisco Estuary.

Keywords: non-native species, sessile invertebrates, temperature, salinity
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What is California Department of Water Resources' Spatially Intensive (GRTS) Benthic Sampling Telling Us? A Clearer Picture of Bivalve Reality

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The exotic, invasive estuarine clam (*Potamocorbula amurensis*) and freshwater clam (*Corbicula fluminea*) are important in the bay and delta food web due to their aggressive removal of phytoplankton and organic particles from the water column and their potential to limit habitat restoration. A spatially intensive benthic program (GRTS, administered by the California Department of Water Resources) that samples 175 sites in May and October, allows us to examine spatial and seasonal patterns in the biomass, growth, and recruitment of both clams over an eight year time period (2007-2012, 2014-2015). The spatially averaged biomass at salinity-appropriate sites for *Corbicula* (6-20 g ash-free-dry mass/m^2) was 2-40 times greater in magnitude than that of *Potamocorbula* (0.5-6 g AFDM/m2); biomass averages within geographic areas were generally consistent with this trend.

Potamocorbula biomass was seasonally dynamic in the shallow water; spatially averaged annual biomass in October in Grizzly Bay (2-7.6 g AFDW/m^2) was up to 40 times that in May (0.1-1.6 g AFDW/m^2). Maximum *Potamocorbula* biomass occurred in Suisun Marsh (143 g AFDM/m2) with the maximum *Potamocorbula* biomass for six of the eight years occurring here. Juvenile abundance was highest in Grizzly Bay (4800/0.05m^2) and weakly present in the confluence. Largest individuals of *Potamocorbula* were found in the upstream locations (10-18mm shell length), possibly reflected fast growth and or low predation/mortality rates on the adults in this region.

Corbicula biomass was more seasonally stable and the seasons were reversed (average annual spring biomass was 1-2 times greater than fall biomass). Maximum biomass was observed in the sloughs east of the San Joaquin River (3800g AFDM/m2) in 2015 and in the sloughs around the Sacramento River (500 g AFDM/m2) in 2007. Juvenile *Corbicula* occurred in all geographic regions during both seasons. Largest individual *Corbicula* were observed in Suisun Marsh (20-30 mm).

Keywords: bivalves, Corbicula, Potamocorbula, GRTS, biomass, grazing, juveniles, size
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Understanding a Drought Induced Die-back of Lepidium latifolium in Invaded Tidal Marshes

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Invasion by noxious weeds is a major conservation and management concern in tidal wetlands. When developing management strategies for these invaders, we must consider the impact of extreme climatic events, such as climate change-induced drought. A particularly problematic invader in San Francisco Bay Delta Estuary is *Lepidium latifolium* (white top). We monitored *Ledpidium* populations from 2014-2016. Between 2014 and 2015, near the peak of California's historic drought, we observed a significant decrease in *Lepidium* stem count ($p<0.05$), stem height ($p<0.05$), and percent cover ($p<0.05$). In order to understand the connection between this invasive plant dieback and drought, we established a manipulative experiment in winter 2016 at the Palo Alto Baylands Nature Reserve, where we altered precipitation in invaded salt marsh plots. We applied four precipitation treatments in a randomized block design (N=6/treatment): rain exclusion (rainout shelter), rain exclusion control (rainout shelter with reirrigation), rain addition (2" of additional water added), and unmanipulated control. Plots were assessed after removal of rainout shelters for stem count and height of *Lepidium*, height of native plants, and percent cover of all plant species. *Lepidium* stems were harvested to assess above ground biomass production within plots. Stem measurements differed between treatments, but covaried with the stem measurements in the plots the previous year. As climate continues to shift and become more variable, understanding how invasion interacts with these changes will likely be critical to effectively managing the *L. latifolium* invasion and preserving these important tidal habitats.

Keywords: Invasion, drought, Lepidium latifolium, tidal marsh, salt marsh, invasive plant
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