Assessing Food Quality of Non-Algal Particles in the San Francisco Bay Estuary and Delta

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Estuarine food web dynamics are complicated by multiple organic carbon sources, including riverine dissolved (DOC) and particulate organic carbon (POC), DOC and detritus from wetlands, algal primary production, and an influx of marine organic carbon. A decline in food quantity and quality inevitably leads to declines in native fish stocks, but predicting impacts cannot be made by simply quantifying changes in the total bioavailable organic carbon in the system, as trophic transfers to preferred prey also must be considered. The decline in native fish in the San Francisco Bay Estuary/Delta (SFBE/Delta) is likely tied to a similar decline in their primary feedstock, i.e. zooplankton, which in turn is likely declining because of decreases in the quantity and quality of the POC on which they feed. Among the many debated issues on Delta ecology, carbon cycling, and foodweb dynamics, the relative importance of algal-derived POC vs. riverine non-algal POC as feedstock for zooplankton is not well-constrained. However, from a mass balance consideration, it seems clear that algal POC alone is not sufficient to support zooplankton abundance, and that both algal and non-algal POC must have a quantitatively important role. This study investigates the detrital/non-algal component of particles in the SFBE/Delta to assess whether increased detrital production from future restored wetlands can be quantitatively large enough to increase zooplankton production, and hence native fish populations. We sampled particles monthly at numerous stations over the course of two years in conjunction with annual fish trawls, and our carbon quality analyses include elemental carbon and nitrogen, lignin, and optical characteristics. Relationships between lignin parameters and total suspended sediment suggests that as the quantity of non-algal POC increases, the quality likely does as well. Thus the benefits of increased particles in the Delta toward zooplankton production is greater than simply higher concentrations of POC.

Keywords: Food web, particulate organic carbon, lignin, optical characterization
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Limnology of the Sacramento Deepwater Ship Channel

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The Sacramento Deepwater Ship Channel (SDSC) supports relatively high fish densities, including all life stages of the endangered delta smelt (*Hypomesus transpacificus*) population. And yet, little is known about how its temperature, specific conductance, turbidity, suspended solids, nutrients, and the abundance and taxonomic composition of its plankton community vary spatially and seasonally. This talk will present information on these and other limnological properties of the SDSC using data collected monthly during 2012-2013. These data will be used to inform and provide a baseline for experiments focused on increasing the food supply of the North Delta.

Keywords: Delta, food, Sacramento Ship Channel, nitrogen limitation
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Estimating Mass Flux of Dissolved Inorganic Nitrogen and Chlorophyll-*a* at Blacklock Marsh, a Restored Site in Suisun Marsh

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Constructed breaches in levees that surround land, previously used for agriculture or duck ponds, have been increasing in the San Francisco Bay-Delta. Often the restoration goals are to improve water quality and to create highly productive habitats for species of concern like the delta smelt. With higher residence times for phytoplankton in tidal marshes, these autotrophs may assimilate high concentrations of dissolved inorganic nitrogen (DIN) into labile organic matter. Still, few studies have quantified the contribution of phytoplankton of individual restored marshes that may be augmenting the base of the pelagic food web. A detailed investigation of tidal variability in water quality parameters including DIN and phytoplankton biomass took place over two summers in a restored site, Blacklock Marsh, in Suisun Marsh. The objective was to determine if this restored site serves as a sink or source for DIN and chlorophyll-*a*. High frequency sampling was conducted over four flood-ebb cycles and two 14-day tidal periods. The concentrations of constituents in the sampled water, along with volumetric changes, were used to calculate the individual net mass fluxes. During all monitored cycles, ammonium, chlorophyll-*a* and suspended sediment concentrations fluctuated inversely with the tides suggesting that the benthos may have contributed significant amounts of these constituents. For the first fortnightly sampling period, preliminary calculations suggest that DIN may be exported and imported depending on the nitrogen species. Results from this study will determine how the marsh is serving as a sink or source of phytoplankton (i.e. organic matter) to neighboring waters. High frequency sampling and net mass flux calculations at restoration sites like Blacklock Marsh will increase understanding of nutrient cycling and help managers predict how future wetland restoration efforts affect nutrient and organic matter loads on a regional scale.

Keywords: wetlands, breach, chlorophyll-a, nitrogen, restoration, water quality
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Vertical Distributions of Phytoplankton in San Francisco Bay

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Temperate lakes and oceans become stratified in spring when heat input creates a warm (low density) surface layer overlaying a cool (high density) bottom layer. Phytoplankton biomass grows in the sunlit surface layer as long as nutrients are available. Once the nutrient stocks are depleted phytoplankton growth becomes nutrient limited in the surface layer and remains light limited in the bottom layer. The interface between the surface and bottom layer can be a narrow zone that provides sufficient light and nutrients to support phytoplankton growth, leading to formation of a subsurface chlorophyll maximum (SCM). A substantial fraction of the primary production of stratified lakes and oceans occurs in the SCM, so it is ecologically significant. What about estuaries like San Francisco Bay that have high nutrient concentrations and intermittent stratification – do SCMs form in these kinds of environments? We analyzed vertical profiles of calibrated chlorophyll fluorescence (a proxy for phytoplankton biomass) collected in San Francisco Bay from 1990-2014 to answer the following questions: (1) do SCMs form in the Bay; (2) are there characteristic depths where SCM's are found; (3) is there a seasonal pattern to SCM formation; (4) are there patterns of change in the occurrence of SCMs over time? Answers to these questions have important implications for designing sampling programs to measure phytoplankton biomass in the Bay.

Keywords: Phytoplankton, Vertical Distribution, Subsurface Chlorophyll Maximum, Stratification, San Francisco Bay
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High Frequency Variability of Phytoplankton and Zooplankton Communities in the San Francisco Estuary

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Estuarine fishery production in San Francisco Estuary is low and has declined over the past decade. It is hypothesized that the decline in fishery production was partly caused by poor production at the base of the food web. However, the production at the base of the food web is poorly known due to low frequency spatial sampling. To address this gap in knowledge, high frequency variation of phytoplankton and zooplankton community composition and biomass in relation to water quality conditions was determined by discrete sampling at 31 stations, spaced t 1.5 km apart, along a 46.5 km transect in the Sacramento and San Joaquin Rivers between May and November in 2013. At each station, water samples were taken at 1 m depth for phytoplankton community composition and water quality analysis, while zooplankton community composition was determined from vertically integrated pumped samples. Continuous measurements of water quality parameters and photosynthetic efficiency were also collected with an YSI sonde and Phytoflash fluorometer. Transects were characterized by high spatial variability, with large shifts in chlorophyll *a* concentration and species composition within only a few km. Water quality variables varied at a low frequency along transects, but were correlated with the biological patterns. For both rivers, chlorophyll *a* concentration increased with water temperature and light availability. Seasonal variation was high, but many of the species shifts occurred at the same location across months. The high frequency spatial variation of phytoplankton, zooplankton and water quality variables in the Sacramento and San Joaquin Rivers suggested there are “hot spots” of production in the estuary that support local estuarine production, and that understanding mechanisms associated with these “hot spots”, may provide guidance for future fishery management.

Keywords: phytoplankton, zooplankton, high frequency distribution, water quality, transect study
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Biomass and Grazing Rates of Two Exotic Bivalves, *Corbicula fluminea* and *Potamocorbula amurensis*, Show Surprising Variability Over 20-30 Year Sampling Period: What Does it Mean for Future Food Webs?

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Understanding the biomass and grazing rate dynamics of the estuarine bivalve *Potamocorbula amurensis* and the freshwater bivalve *Corbicula fluminea* are important to our understanding of present day food web dynamics and habitat restoration potential within the San Francisco Bay and Delta. Historic benthic monitoring samples (Department of Water Resources Monitoring Program), some from as early as 1975, are providing insight into the long term changes in *C. fluminea* and more recent changes in *P. amurensis* biomass. These biomass data series show that the effects of benthic grazing on pelagic food resources have not been constant. *C. fluminea* populations at three stations located in the Central Delta (D16, D28) and near Clifton Court (C9), showed dramatic declines in biomass and average clam length in 2001-2002 concurrent with the decline of several fish species in the ecosystem. The cause of these biomass and size declines is unlikely to be a reduction in phytoplankton biomass as chlorophyll *a* declined in 1994 and has remained relatively constant since then. Either increased predation on the bivalves or a decline in another food resource could result in the biomass patterns observed. Bivalves at stations located on the Sacramento River (D24), on the San Joaquin River (P8), and at the confluence of the rivers (D4) showed very different patterns. Bivalve biomass greatly increased at D24, declined at D4, and remained consistently low at P8. Within the bay, the Grizzly Bay population of *P. amurensis* developed a regular seasonal pattern of biomass change about six years after its invasion and the San Pablo Bay (D41A) *P. amurensis* populations have begun to show great interannual variability in biomass. Variable timing in bivalve grazing may result in short windows of opportunity for phytoplankton to grow as has been observed in Grizzly Bay and San Pablo Bay.

Keywords: bivalve, food-limited, *Corbicula, Potamocorbula*, long-term, biomass, grazing
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Clam Grazing and Suisun Bay Blooms Modeled with Nitrogen as Currency.

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The invasive clam, *Potamocorbula amurensis*, has been cited as the cause of reduced phytoplankton biomass and productivity in Suisun Bay, CA. Comparison of *in situ* clam grazing rates, calculated from laboratory determined filtration rates, and the biomass of clams and phytoplankton, with calculated phytoplankton growth rates suggests that in Suisun Bay, phytoplankton blooms could only occur rarely. However, spring blooms do occur in Suisun Bay, quite regularly in the shoals of Grizzly Bay and occasionally in the deep-water channels, indicating that growth rates of the phytoplankton do exceed clam grazing rates at times. An alternative way to assess the role of clams in Suisun Bay primary production is by utilizing a nitrogen-based model. Spring phytoplankton bloom development in the Suisun Bay requires first improved irradiance conditions followed by a decline in ammonium concentrations (due to phytoplankton uptake) that enables phytoplankton to access the greater concentration of DIN, nitrate. If clam grazing removes phytoplankton biomass at an equivalent or greater rate than the ammonium uptake rate by phytoplankton, ammonium concentrations will not decrease and blooms are prevented. Calculations show that to allow blooms, the *in situ* clam filtration rate must be less than 10% of the published laboratory values. Simulations were made of the Grizzly Bay spring bloom with varying concentrations of clams to estimate threshold levels of clam populations that could control blooms. These results are relevant to the question of the importance of clams and elevated ammonium as major environmental factors holding primary productivity to low levels in Suisun Bay and serving as possible factors in the Pelagic Organism Decline. Effective management of the estuary will require a basic understanding of the regulation of primary production in the northern estuary.

Keywords: clam, phytoplankton, Susiun Bay, nutrients, model
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Increased Algae Concentration Broadens the Tolerance of a SFE Copepod to Salinity

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Concentrations of phytoplankton have dropped substantially in the SFE, at least partially due to invasions by exotic bivalves. As salinity increases in the SFE with climate change, it is unclear how zooplankton will respond, and whether decreased food concentration will play a role. Here, we examined how algal concentration and salinity affect food consumption, growth, and survival of *Eurytemora affinis*—a key prey species for the delta smelt and other species of conservation concern. In a series of laboratory experiments, we found that increasing the concentration of algae substantially increased the tolerance of *E. affinis* to both high and low salinity. To determine whether this food by salinity interaction was due to an enhanced ability to osmoregulate at higher levels of food, we measured growth and food consumption of *E. affinis* at 4 and 8g/L salinity at low and moderate feeding rates. At the lower level of feeding, we found that growth rates were 2-fold higher at 4 than 8g/L, while rates of food consumption were similar. At the higher level of feeding, we found that growth rates were nearly identical between the two salinities, but the rate of food consumption was 3 times higher at 8g/L. Both of these results demonstrate that the energy requirements of *E. affinis* increase dramatically at non-optimal salinities, likely due to the energetic costs associated with osmoregulation. When food is limited, growth is sacrificed in favor of osmoregulation. When food is abundant, far more food is consumed, allowing copepods to both osmoregulate and grow rapidly. Our results suggest that invasive clams are likely to decrease the salinity tolerance, and therefore range, of *E. affinis* by limiting their ability to osmoregulate.

Keywords: Eurytemora affinis, salinity, phytoplankton, climate change, invasive clams, tolerance, osmoregulation
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Elemental and Isotopic Composition of Submerged Aquatic Vegetation in Suisun Bay and the Delta: Spatio-Temporal Patterns and Food Web Support

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Recent surveys in Suisun Bay and the west Delta recorded more than 1100 acres of native *Stuckenia* spp. (pondweeds) at locations where submerged aquatic vegetation (SAV) was previously assumed minimal. This prompted efforts to assess the potential of these SAV beds to provide habitat and food web support for native fish. Stable isotope (SI) analysis is a powerful tool in ecological research, now increasingly used to study nutrient fluxes and food webs in aquatic ecosystems. However, identifying the sources of organic matter supporting food webs in ecosystems as dynamic as estuaries requires a sound understanding of the variability of these sources. Here we document spatial and temporal patterns in the carbon, nitrogen and sulfur elemental and stable isotope composition of 9 primary producers including *Stuckenia* spp. and the invasive *Egeria densa*. SAV species were sampled quarterly at 8 sites across the low salinity zone of the San Francisco Estuary from fall 2011 to fall 2012. As expected, some inter-species differences were detected, as well as large seasonal and/or inter-site variations in some species, probably due to a combination of hydrodynamic (freshwater flow directly controlling the position of the salinity gradient relative to SAV beds and indirectly controlling the isotopic signature of the nutrient sources through mixing and residence time) and physiological processes (growth rate and tissue isotopic turnover rate). Moreover, Bayesian stable isotope mixing models further highlighted the need for thorough sampling strategies in SI studies, as the estimated diet of the main invertebrate species varied greatly across sites (e.g., the green macroalga *Cladophora* always significantly contributing when present, but replaced by *Stuckenia* if absent). These results and follow-up studies will help improve our understanding of the trophic relationships in the SAV beds of the upper San Francisco estuary, providing insights into conservation and management strategies for these habitats.

Keywords: food web, stable isotopes, submerged aquatic vegetation, Stuckenia, mixing model
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Effects of Variable Freshwater Flow on Fish and Foodwebs of the San Francisco Estuary

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Freshwater flow is a dominant driver of estuarine change. Conflicts over allocation of freshwater require that we understand mechanisms for flow effects on the estuary to support effective management. We present some recent findings about mechanisms for flow effects on estuarine biota. These results show that interactions between hydrodynamics and organism behavior can have a strong influence on maintenance of biological populations. Foodweb organisms such as copepods and mysids behave in ways that take advantage of flow conditions to minimize losses. Freshwater flow can transport organisms within the estuary, but does not appear to stimulate the foodweb through effects on primary production. Our fall habitat studies show that growth and reproductive rates of the copepod *Pseudodiaptomus forbesi* were unaffected by flow but responded to a brief pulse of phytoplankton biomass transported into the lower Sacramento River. In addition, abundance in this copepod's freshwater population maximum was unaffected by flow, possibly because of vertical migration behavior. Abundance in brackish water increased slightly with increasing flow as a result of transport from the central Delta. However, apparent mortality rate of early life stages was lower in the high-flow 2011 than in two other years, because of a combination of increased subsidy from freshwater and possibly reduced consumption by clams and the predatory copepod *Acartiella sinensis*. Thus, the response of the foodweb to variable freshwater flow was indirect and complex, and would be difficult to interpret without information on transport, predation, and growth rates. Nevertheless, it is feasible to build models that incorporate these effects to allow for predictions of flow effects and possibly refining the efficacy of flow-based management.

Keywords: freshwater flow, copepod, foodweb, population dynamics, modeling
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