Salinity Pattern in Indian Estuaries Regulating Alien Anisakid Species Invasion in Fish

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The emerging challenges from change in the salinity pattern in estuarine zones to trigger the transmission of invasive species of zoonotic significance, from coastal wetlands in the Central West coast of India (showing wider host specificity), to the fresh water of river Ganges (showing stricter host specificity in *Rita rita*), have been noticed. The anisakid species, *Iheringascaris goai* (Malhotra et al., 2011) was recorded since 2001, from sharks, *Rhyncodon typus* and catfish, *Arius maculatus* and *I. inquies* (Linton) recorded earlier. The molecular analysis, including 18S rRNA and coI, of these and one other anisakid worm indicated emergence of morphological peculiarities, and hence diversity of species, under the environmental influence. Wide variations in salinity *vis-à-vis* seasonal periodicity at Mandovi estuary revealed 37-40 ppt during summer period (May-June), while 29-34 ppt salinity occurred in rainy and winter periods. Jhingran (1991) emphasized that in Zone IV (i.e. estuarine zone of Rupnarayan near Bay of Bengal), salinity decline occurred after construction of Farakka Barrage (1975 upto 1977), because of freshwater being flushed into estuarine water. But later, in the Zones II and III during 1988-1992 and 1994-1998, the salinity values escalated, and these fluctuations resulted into change in fauna as well as vegetation. Heavier dredging operations before 2001 to facilitate Shipping Corporation of India activities, could easily become an instrument of changed copepod fauna due to major shifting of sand from the bottom to the surface of the riverine stretch from Haldia (West Bengal) upstream River Ganges upto Saraswati Ghat at Allahabad (Uttar Pradesh). Thus, extension of predominant freshwater characteristics of the estuarine zone in the areas upstream River Ganges could have facilitated the outreach and survival of changed intermediate copepod host populations up to Allahabad. This possibly facilitated sudden survival and establishment of a newer anisakid species that possessed the characteristics of the invader anisakid genera from the Arabian Sea.

Keywords: Invasive Species, Indian Ocean, River Ganges

Poster Topic: Invasive Species

Population Persistence of the Invasive Suspension-Feeding Bivalves *Potamocorbula amurensis* and *Corbicula fluminea* in San Francisco Estuary: What Can We Learn about Future Spread and Impacts?

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The invasion of *Potamocorbula amurensis* into San Francisco Estuary was remarkably successful, and it affected ecosystem function almost immediately. We know less about the immediacy of the effect of *Corbicula fluminea* when it invaded in the 1940s, but we know that both bivalves can reduce phytoplankton biomass in the present system. Today, these two invasive bivalves overlap in the biologically sensitive low salinity zone and they jointly populate the system from the Delta to San Pablo Bay.

Here, we use the California Department of Water Resources (DWR) spatially intensive benthic sampling program (GRTS) to examine the biomass distribution of both species in spring and fall of 2007 through 2012 to identify the environmental factors associated with their distributions. We show that the location of the dominant region of overlap is mostly controlled by the salinity distribution at the time of larval clam settlement. However, post-juvenile clams may persist outside this location due to increasing salinity tolerance in adult clams which accounts for the wide range of overlap of adult clams. Variability in the magnitude of biomass and grazing rate is related to environmental conditions during reproduction and growth seasons in the present year and extreme environmental events in the prior year for both species. The grazing rate to tissue mass relationship is non-linear and the grazing rate is relatively larger in *P. amurensis* than in *C. fluminea* for a similar biomass. Thus, the biomass distribution of each species does not directly translate to a similar distribution of grazing rate. We calculate biomass, grazing rate, and water turnover rate for all sampling periods. We augment the spatial data and supply temporal context to the spatial data with time series data from the DWR Environmental Monitoring Program stations that are sampled monthly.

Keywords: Bivalve, *Corbicula, Potamocorbula*, Grazing Rate, GRTS, San Francisco Estuary

Poster Topic: Invasive Species

Three Non-native Jellyfish in the San Francisco Estuary: Distribution, Abundance, and Potential Impacts

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Three species of jellyfish indigenous to the Black Sea (*Blackfordia virginica, Maeotias marginata,* and *Moerisia lyonsi*) have become established in low-salinity habitats of the San Francisco Estuary (SFE). All three jellyfish spatially and temporally overlap with protected planktivorous fish, and share a similar diet consisting primarily of copepods. This study quantifies the distribution and abundance of all three species within four brackish-water tributaries of the SFE from early summer to late fall during 2010 and 2011. Jellyfish and their prey were sampled weekly or biweekly and environmental variables were recorded. The upper quartile abundance for *B. virginica* was 95 medusae m^{-3} in 2010 and 115 medusae m^{-3} in 2011, exceeding previous reports of <5 medusae m^{-3}. The upper quartile abundance of *M. marginata* (2 medusae m^{-3} in 2010 and 2011) and *M. lyonsi* (13 medusae m^{-3} in 2010 and 50 medusae m^{-3} in 2011) are similar to previous reports. Information on abundance was combined with feeding rates measured in the laboratory (*B. virginica* and *M. marginata*) or taken from the literature (*M. lyonsi*) to estimate predation impacts. The highest potential impact was 20–60% of the water column cleared per day estimated for *B. virginica,* which is higher than the population growth rates of their copepod prey. As a result hydromedusa populations in the SFE have the potential to locally depress copepod populations, potentially reducing prey available for protected species of fish.

Keywords: *Blackfordia virginica, Maeotias marginata, Moerisia lyonsi*, Abundance, Feeding, Gelatinous Zooplankton

Poster Topic: Invasive Species

Abundance and Distribution of Gelatinous Plankton in the Northern San Francisco Estuary

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Until recently, gelatinous zooplankton were not considered important components of the San Francisco Estuary (SFE) foodweb. However, anecdotal evidence, ongoing research, and a few published reports and papers suggest an increase in their abundance over the last 10 to 20 years. Of particular interests are three species of introduced hydromedusae (*Blackfordia virginica*, *Maeotias marginata*, and *Moerisia lyonsi*). All three inhabit the fresh to brackish regions of the estuary, including Suisun Bay, the channels of Suisun Marsh, and the western Sacramento-San Joaquin Delta, and are seasonally abundant throughout late summer and fall. As a result, they overlap both spatially and temporally with several species of planktivorous fish, including delta smelt. Changes in the abundance and distribution of gelatinous zooplankton may strongly influence their interactions with fish, including consumption of fish eggs and larvae and competition for zooplankton prey. Here, we report the distribution and abundance of gelatinous zooplankton at 9 stations throughout the northern SFE during late summer and fall of 2011 and 2012. While work in four smaller tributaries (see Donald et al.) reports high abundances (>50 m^{-3}) of two species (*B. virginica* and *M. lyonsi*), abundances of these and other species in the larger bays (San Pablo and Suisun) and rivers (Sacramento and San Joaquin) were significantly lower (<1 m^{-3}). Most of the previous work to define the habitat range (salinity and temperature) of these species has occurred within Suisun Marsh. Extending this work into the open bays will help provide a more accurate habitat description. Additionally, information on the distribution and abundance of gelatinous zooplankton and how these vary with X2 will provide insight regarding the potential for interactions between gelatinous zooplankton and protected fish species within the SFE.

Keywords: Jellyfish, Invasive Species, *Blackfordia virginica, Maeotias marginata*, *Moerisia lyonsi*

Poster Topic: Invasive Species

Salinity Tolerance of the Copepod *Pseudodiaptomus forbesi*

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Distributions of estuarine organisms are dictated in part by physiological tolerances to salinity, but salinity is not the only factor that determines where species are found. Historical records from the Interagency Ecological Program long-term zooplankton monitoring program show that the introduced calanoid copepod *Pseudodiaptomus forbesi* was once abundant across a broader range of salinity than where it is currently found in the San Francisco Estuary (SFE). Previously this copepod was abundant from freshwater to waters of salinity 5 and higher, however now it is generally found in waters less than salinity 5 and is most abundant in waters of salinity less than 1. This study examined how salinity affects both the survival and reproduction of this copepod, as knowledge of reproductive parameters is crucial to understanding and predicting population dynamics. Laboratory experiments on the acute salinity tolerance of this species indicated that it is physiologically capable of tolerating a much wider range of salinity than it currently inhabits in the SFE. Furthermore, experiments on reproductive output of *P. forbesi* indicate that it is more productive at salinities around 5-8 than it is at salinities 0-2, yet in the SFE it is far more abundant at the lower salinities. This study presents an example of an estuarine organism whose distribution is not shaped by physiological tolerance to salinity but rather by other factors such as interspecific interactions. Understanding the factors that affect species distribution allow for more accurate modeling of the system under current and future conditions. In particular, since copepods are an important lower-trophic link, understanding the distribution of copepods provides insight into the resources available to higher trophic levels.

Keywords: Salinity, Copepod, Distribution, Delta, *Pseudodiaptomus*, Ecology, Physiology, Invasive

Poster Topic: Invasive Species

Assessment of Revegetation of Tidal Marshes Following Invasive Spartina Control

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The colonizing of non-native species of *Spartina alterniflora* (smooth cordgrass) across the San Francisco Bay Estuary presents a conflict between balancing removal efforts while maintaining habitat for sensitive species such as the California Clapper Rail (*Rallus longirostris obsoletus*). Understanding tidal marsh's ability to revegetate following invasive *Spartina* control, is one component in understanding population trends of Clapper Rails in the Bay, while helping guide future efforts to control invasive *Spartina*.

To investigate the revegetation of San Francisco Bay marshes, we compared vegetation assessments collected in 2005, prior to the main *Spartina* eradication efforts, to assessments in the same marshes in 2011, post-eradication. Vegetation cover in the 2005 sampled plots used estimates generated from aerial imagery; this method was also applied to a subset of the 2011 plots, to compare accuracy to field collected data. The sampled plots could then be compared for changes in vegetation cover and composition of species. To investigate how *Spartina* control affected the Clapper Rail, we examined within and between marsh site use, in relation to vegetation cover in 2005.

A total of 183 points were examined for changes in cover and species composition. The comparison between aerial estimates and field estimates for 90 of the 2011 points were similar, averaging an 8.18% difference. Results show significant declines in *Spartina* cover, and increases in native vegetation, particularly *Sarcocornia pacifica* (perennial pickleweed).

Results show marshes possess the ability to rebound relatively quickly from invasive *Spartina* control, and native vegetation will recolonize the historic marsh plain. While we know the Clapper Rail is sensitive to local habitat changes and that there appeared to be a population wide impact following *Spartina* control, investigating this relationship using this dataset provides a novel approach to inform management of invasive *Spartina* and maintain viable Clapper Rail populations.

Keywords: Invasive Cordgrass Control, Spartina, Clapper Rail, Passive Revegetation, Tidal Marsh

Poster Topic: Invasive Species

Approaching Eradication of *Spartina densiflora* from the San Francisco Estuary: Successful Adaptive Integrated Pest Management

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Spartina densiflora (Chilean cordgrass) was introduced along Corte Madera Creek, Marin County in 1975 as part of a wetland restoration. Misidentified as a variant of native *Spartina foliosa* (Pacific cordgrass), it was subsequently imported from Humboldt Bay where it had been introduced in dry ballast deposited there during the 19th century timber trade with South America, sparking an infestation now dominating 2000 acres.

By 2004, *S. densiflora* dominated much of the Corte Madera Creek marshes and had spread throughout east Marin and across to eastern San Pablo Bay. The Invasive *Spartina* Project and Friends of Corte Madera Creek Watershed began treatment on these infestations in 2004-2006, relying predominantly on imazapyr herbicide in the initial years to gain control of the problem. Several major challenges to eradication quickly became evident. Entry into many infested marshes was restricted until the end of endangered California clapper rail breeding season on September 1, but *S. densiflora* sets seed by July, so that initial timing made it impossible to stay ahead of the infestation. To make matters worse, imazapyr produced extremely variable results on *S. densiflora*, although it worked exceptionally well on ISP's main target, hybrid *S. alterniflora.* Imazapyr arrested plant development in established monocultures of *S. densiflora*, but full mortality was rarely achieved, and seedlings/small plants with a higher root to leaf surface area ratio presented similar issues.

These mixed results required adaptation of the IPM strategy, combining multiple treatment tools and approaches to achieve success. In 2009, mowing was evaluated on the persistent, half-dead biomass remaining at monocultures of previously-sprayed *S. densiflora*. This elicited fresh green growth from plants that were still alive, identifying targets for retreatment with imazapyr or digging. Around the Estuary, treatment shifted to purely manual removal by ISP biologists to exhaust the seed bank and maintain an eradication trajectory.

Keywords: *Spartina*, *Spartina densiflora*, IPM, Integrated Pest Management

Poster Topic: Invasive Species

HACCP (Hazard Analysis and Critical Control Point Planning): A Risk Management Tool to Decrease the Movement of Invasive Species

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Without appropriate planning, activities that take biologists and their equipment to different habitats, including habitat restoration, monitoring, biological surveys, or collections, could be pathways for the spread of nonindigenous species. It is our responsibility as natural resource professionals to strive to do no harm by understanding invasive species pathways and developing plans to prevent future spread.

Hazard Analysis and Critical Control Point (HACCP) planning is a five-step tool that manages the risk of moving invasive species during natural resource management activities. The steps involve recognition of non-target, or potentially invasive, species, risk management and assessment of potential pathways, identification of critical points where there may be a risk of introducing a non-target species, and development and evaluation of control measures used to reduce this risk to an acceptable level. By following these steps, HACCP is designed to identify high-risk activities and focus attention on those actions needed to close open pathways. Plans documenting the risk posed by an activity for moving invasive species, as well as control methods used to reduce these risks, give managers the opportunity to weigh the benefits from natural resource actions against the risk of invasion. HACCP plans also create a reference source for documenting best management practices and procedures that can be shared with others to reduce this risk of invasion through pathways with similar characteristics

In 2011, an updated HACCP course was completed that incorporates comments and suggestions from previous courses (please visit http://www.haccp-nrm.org for more information). In addition to the standard HACCP course which focuses on the development and implementation of HACCP plans, a new Train the Trainer course has been developed for new HACCP instructors. Upcoming course information is available from the U.S. Fish and Wildlife Service's National Conservation Training Center located in Shepherdstown, West Virginia.

Keywords: HACCP, Invasive Species

Poster Topic: Invasive Species

Compliance of Ballast Water Management for Commercial Ships Operating in the San Francisco Estuary

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The discharge of ballast water from commercial ships is a well-known and highly documented vector for the introduction of nonindigenous species (NIS) to California waters, especially within the San Francisco Estuary (SFE). It is estimated that up to 81% of California's 257 established aquatic NIS were introduced via commercial shipping, both through ballast water discharge and/or release of associated biofouling. In order to address this, the California State Lands Commission's Marine Invasive Species Program (MISP) has pursued the prevention of NIS release from commercial vessels into California waters since 2000. A vital information-gathering component of the MISP is the requirement that vessels submit ballast water reporting forms upon departure from each port or place of call in California. These forms detail ballast water management activities for the approximately 3,700 vessel arrivals to SFE ports each year, forming a robust data set through which compliance and management patterns can be examined. An analysis of ballast water management compliance at SFE ports from 2008-2012 will be presented including geographic and temporal analyses of source and exchange patterns of ballast water that is eventually discharged within the estuary. The analysis will also include a description of how these data are used to help MISP staff to reduce the risk of future NIS introductions.

Keywords: Nonindigenous Species, Ballast Water, Commercial Shipping

Poster Topic: Invasive Species: Commercial Vessels

Risky Business: Comparative Nonindigenous Species Risk from Vessels at San Francisco Estuary Ports

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Nonindigenous species (NIS) are organisms introduced through various human activities to an area where they do not naturally or historically occur. Once established, NIS can have severe ecological, economic, and human health impacts on the receiving environment. One of the most severely invaded ecosystems in North America is the San Francisco Estuary (SFE); roughly 65% of California's currently established marine NIS were first documented in the SFE. In coastal environments, commercial shipping is the most important vector of NIS introductions, contributing up to 79.5% of introductions to North America and up to 81% in California. Commercial ships transport organisms through two primary mechanisms: ballast water and vessel biofouling. The State Lands Commission Marine Invasive Species Program (MISP) tracks vessel arrivals at seven commercial port regions within the SFE. These arriving vessels pose varying levels of risk for introducing NIS from ballast water discharge and biofouling accumulation. Analyzing data collected by the MISP on vessel ballast water and biofouling management from 2008 to 2012 will allow us to identify patterns in management for the vessels arriving in the SFE. These management patterns can help us understand the potential invasion risk within the estuary.

Keywords: Nonindigenous Species, Ballast Water, Biofouling, San Francisco Estuary, Invasion Risk

Poster Topic: Invasive Species: Commercial Vessels

Hull Husbandry Patterns of Commercial Vessels Operating Within the San Francisco Estuary: Implications for Vessel Biofouling and Species Introductions

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Commercial shipping is a major industry within the San Francisco Estuary (SFE), as more than 3700 vessels arrive annually to the seven major ports within the SFE. Because shipping is a global industry, this activity brings goods, jobs, and revenues to California from all over the world. Unfortunately, shipping also brings nonindigenous aquatic organisms from all over the world into the SFE through the combined shipping-related mechanisms (vectors) of ballast water and biofouling. Once established, these nonindigenous species (NIS) can have deleterious effects on their receiving environment.

It is widely recognized that the SFE is one of the most heavily invaded water bodies in the world, with approximately 200 aquatic NIS (excluding vascular plants and vertebrates) currently established. This pattern is partially a result of the heavy shipping traffic to ports within the SFE, as up to 62% of currently established NIS in SFE are attributed to biofouling as a likely vector. In order to address the continued risk of NIS introduction through the vessel biofouling vector, the California State Lands Commission's Marine Invasive Species Program has been collecting annual ship-reported biofouling management data from each vessel operating in the state. An analysis of this multiyear dataset will be presented, describing patterns in vessel biofouling management specifically for the vessels that operate within the SFE. The analysis will also include a description of how these data are being used to inform the development of biofouling management regulations for vessels operating in California, to reduce future NIS introduction risk.

Keywords: Invasive Species, Nonindigenous Species, Biofouling, Shipping, Vessels, Vector, Vector Management

Poster Topic: Invasive Species: Commercial Vessels