Science Foundation Chapter 5
Appendix 5.1 – Case Study
Marsh Macroinvertebrates

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DESCRIPTION OF THE SPECIES

This case study includes representative macroinvertebrates that live in the marsh plain, its associated channels and pannes (ponds), and the marsh-upland transition zone. While less visible than animals such as birds, invertebrates play important roles in physical and biological processes (e.g., burrowing activity and channel bank erosion, and detritivores breaking down organic matter) and are important food resources for higher trophic animals. Common invertebrates in these habitats include plant-hopper (*Prokelisia marginata*), beach hopper (*Traskorchestia traskiana*), pygmy blue butterfly (*Brephidium exilis*), inchworm moth (*Perizoma custodiata*), western tanarthus beetle (*Tanarthus occidentalis*), salt marsh mosquitoes (*Aedes* spp.; Maffei 2000a, Maffei 2000b, Maffei 2000c), crabs (native *Hemigrapsus oregonensis* and introduced *Carcinus maenas*), copepods, snails (e.g. native California horn snail *Cerithidea californica* and introduced *Ilyanassa obsoleta, Myosotella myosotis*), polychaetes (e.g. *Capitella* spp., *Eteone californica, Neanthes brandti*), small clams (*Macoma petalum/M. balthica*), and corophiid amphipods (Cohen 2011, Race 1982, Robinson et al. 2011). Some common species were described in detail in the San Francisco Bay Goals Project *Species and Community Profiles* (Goals Project 2000).

CRITERIA FOR SELECTION OF THE GUILD

This broad group of organisms serves a variety of ecological roles. Some species are food for songbirds, shorebirds, waterfowl, fish, or small vertebrates (Goals Project 2000, Dean 2005, Robinson et al. 2011). Others pollinate plants or scavenge dead vegetation. The introduced isopod *Sphaeroma quoianum* can increase erosion of marsh channel banks through its burrowing (Talley and Levin 1999). Some species distributions are restricted to narrow habitats. Others provide a link between the marsh and upland habitats by traveling between them (Maffei 2000d). Many are poorly studied; therefore, this case study focuses on species for which we could find sufficient information. Climate change may create negative impacts on some species and positive impacts for others, depending on their ecology and the physical changes experienced by marshes in coming decades.

OTHER INFORMATION ABOUT THE SPECIES

Each invertebrate species tends to have a preference for particular environments within the marsh, such as the marsh plain, channels, or pannes. For example, at China Camp Marsh in the North Bay, corophiid amphipods and the bivalve *Macoma petalum* were found mostly in large channels, while the non-native mussel *Geukensia demissa* inhabited the lower sections of channels at the edge of the marsh (Robinson et al. 2011). While the marsh contains many species, a few of them tend to make up the majority of the numbers and biomass, and in San Francisco Bay marshes many of the most abundant species were introduced from other parts of the world.

Many factors influence where a particular species will be found in a marsh, including physical structure, predation, competition, larval settlement and survival, and disturbance (Kneib 1984). Race (1982) studied competition between California horn snails and introduced *Ilyanassa obsoleta* snails in San Francisco Bay. She found that the marsh pannes (small ponds) provide a refuge for California horn snails when they are outcompeted by *Ilyanassa* on mudflats. Life cycles also influence invertebrate distribution. Many species are dormant during the winter. Species that have larval stages may use different parts of the marsh at each stage, for example with an aquatic larval stage and adults living on vegetation.

Invertebrates have developed a range of physiological and behavioral adaptions for life in the marsh. These include adaptations to survive fluctuations in salinity, temperature, and water levels on a daily to seasonal basis (Parker et al. 2012).

Tidal marshes are highly productive ecosystems and marsh-derived organic matter and nutrients are important food subsidies for aquatic and coastal ecosystems (Teal 1962; Odum1980). Relatively few experimental studies have been conducted on tidal marsh food webs and trophic structure in San Francisco Bay, though see Howe and Simenstad (2007). Stable isotope analysis is a common tool that uses naturally occurring elements to trace food web sources and pathways. Stable isotope analyses showed that food webs for marsh invertebrates (such as filter feeding mussels) depended mostly on inputs from the marsh itself rather than on nutrients from the bay, even in newly restored marshes (Howe and Simenstad 2007, 2011), suggesting that inter-marsh connectivity can play an important role in subsidizing food webs in early marsh restorations. Juvenile fishes forage on insects that fall into the water column from tidal marsh plant canopies, as well as tidal marsh-derived materials that end up in aquatic food webs (Howe and Simenstad 2011; Herbold et al. 2014).

Grenier (2004) used stable isotope analyses within a tidal marsh in San Francisco Bay and conclude that marsh plain macroinvertebrates have fairly simple food chains extending from aphids to wolf spiders (Grenier 2004). The diets of song sparrow (*Melospiza melodia*), California black rails (*Laterallus jamaicensis coturniculus*), and California voles (*Microtus californicus sanpabloensis*) appeared similar, based mostly on the aerial pathway (insects) rather than the benthic (ground) food web pathway (Grenier 2004). This food chain is spatially separated and distinct from benthic invertebrates in the mudflats, which are generally supported by benthic microalgae (Neira et al. 2005).

Food web studies have confirmed the role of cordgrass (*Spartina spp.*) detritus in the diet of surface and subsurface detrital consumers (Levin et al. 2006). Leaf-hoppers, which feed on plant sap, also had a stable isotope composition similar to *Spartina* cordgrass, indicating that cordgrass is their primary food resource. Several recent studies examined the effects of invasive hybrid *Spartina* (a hybrid between San Francisco Bay native *Spartina foliosa* and U.S. east coast species *Spartina alterniflora*) on invertebrate food webs. Hybrid *Spartina* created numerous physical and biological changes to invaded marshes that reduced species richness and density and further changed macroinvertebrate community structure from surface microalgae feeders (i.e., crustaceans and bivalves) to one dominated by belowground plant detritus consumers (oligochaetes; Levin et al. 2006, Neira et al. 2007). The reduction in bivalves, amphipods, and polychaetes within invasive hybrid *Spartina* zones is also a concern because these invertebrates are important food for migratory shorebirds (Levin et al. 2006, Neira et al. 2007). Furthermore, while hybrid *Spartina* added more plant detritus into the marshes where it invaded, invertebrates such as crabs, clams, and mussels did not ingest it, indicating that invasive hybrid *Spartina* did not create a new food source (Brusati and Grosholz 2009) for the key invertebrate prey resources for migratory birds.

REVIEW OF CLIMATE CHANGE EFFECTS ON THE SPECIES

These species already live with periodic natural stresses in the form of tidal cycles and changes in salinity over a day or season. Therefore, the scale of climate change impacts may depend on whether changes are outside the range of variation these species already experience and their ability to adapt. In addition, some stresses caused by climate change may be long-term, such as loss of high marsh, while others may be more periodic, such as changes in inundation periods or seasonal salinity. The impacts described below for different climate change scenarios are educated guesses extrapolated from the available information on macroinvertebrate tolerances to temperature, salinity, and other environmental factors. The description below focuses on the scenarios that are most likely to have an impact on macroinvertebrate communities.

All scenarios: The effect of changes in temperature extremes and temperature fluctuations may depend on how the current climate of San Francisco Bay marshes compares to the physiological tolerances of particular species (Deutsch 2008, Kingsolver et al. 2011). In general, increased temperatures in water, sediment, or ambient air could each affect invertebrates, as the habitats of these organisms differ at different life stages or different parts of the tidal cycle. Not all changes may be negative; warmer temperatures could benefit insects in temperate latitudes by increasing population growth rates (Deutsch 2008). However, if marsh plants that are hosts for insect larvae shift their bloom periods, this could create a disconnection between when eggs are laid and when resources are available for larvae, reducing survival rates (Durant et al. 2007).

Two of the larger macroinvertebrates in salt marshes are native shore crabs (*Hemigrapsus oregonensis*) and invasive European green crabs (*Carcinus maenas*). Both species can tolerate a wide range of temperatures. Shore crabs live in estuaries from Alaska to Baja California, putting San Francisco Bay in the middle of their geographic range and temperature conditions. Therefore, it is likely that they will be able to tolerate increasing temperature, although that assumes that the San Francisco Bay populations are not constrained by being genetically adapted to current conditions here. European green crabs have invaded many places around the world and can tolerate temperatures up to 91° F and reproduce in temperatures up to 79° F (Cohen 2011).

Scenarios 2 and 4 (high sea level rise scenarios): The greatest impact to marsh plain macroinvertebrates will likely be from the conversion of high marsh to low marsh or mudflats due to sea level rise and marsh drowning (if sediment accretion rates do not keep pace with accelerated sea level rise). In most areas around the bay, the area of high marsh and marsh-upland transition zones will decrease as they become compressed between rising sea level and area that lacks upland migration potential, while overall intertidal habitat will likely increase (Strahlberg et al. 2011). Species that depend upon the higher marsh will have less habitat while those that can utilize lower tidal elevations will likely be less affected. Longer inundation periods could be detrimental to some invertebrates but beneficial to others (Robinson et al. 2011), depending on specific life histories. At Tolay Creek marsh in San Pablo Bay, tidal inundation did not affect the number of adult insect species or their vertical stratification on marsh vegetation, suggesting that some insects can remain attached to vegetation when inundated (Cameron 1976). Attaching during inundation may be less energetically costly than migrating out of the marsh and back again with the tidal cycle. Many insects live as adults in the marsh for only a few weeks and so must partition their available energy among development, reproduction, and dispersal in that short time period (Cameron 1976). Reduction in high marsh could reduce host plants available to some insect larva, such as the inchworm moth which lays its eggs on alkali heath (*Frankenia salina*). Loss of their habitat could affect the larval life stage greater than the more mobile adult stage for flying insects. Cameron's study (1976) focused on periodic inundation from tides but could be useful for understanding the possible effects of longer inundation with sea level rise.

Changes in vegetation structure caused either by temperature increases or greater inundation could also affect invertebrate community composition or survival. In a southern California marsh, reduced shade altered the species community and changed the composition of microalgae that provide food to invertebrates, increasing the proportion of insect larvae while decreasing amphipods and oligochaetes (Whitcraft and Levin 2007).

Marsh macroinvertebrates will also need to adapt to changing salinity conditions. Cayan et al. (2008) provide climate projections in which a reduced snow pack and warmer conditions will result in some years with greater runoff (as the result of increased precipitation), and other years with significantly reduced outflow and in particular a shorter runoff season due to reduced late season snow melt. The resulting scenarios indicate increasingly variable salinity in the San Francisco Bay-Delta. Unfortunately, we have little specific information regarding the salinity tolerances of many marsh macroinvertebrates.

Scenario 5 (extreme storm event): Extreme storm events may cause a die-off of vegetation that cannot tolerate increased periods of inundation (Thorne et al. 2013), causing negative impacts on invertebrates living within the vegetation at the time of a storm. This will mostly affect species or life stages that are not very mobile. High storm discharge into tidal marsh creeks could wash away sections of creek banks and displace invertebrates burrowing within them. However, this seems more likely to be a short-term effect on particular marshes.

OTHER STRESSORS

The marsh plain may receive inputs of pollutants from adjacent upland areas. Invasive plants could invade the marsh plain, possibly reducing host plants for some insect species, but the impacts would depend on how specialized those insects are on particular plants. Increased frequencies of extreme winter storms could affect everything from salinity to marsh erosion to pollutants washed downstream from uplands.

ENTIRE LIFE CYCLE AND INFLUENCES FROM OUTSIDE THE ESTUARY

The effects of climate change may impact different life stages in different ways, with varying degrees of severity. The habitat used by macroinvertebrates, especially insects, often differs among egg, juvenile, and adult stages, as do their tolerance for high temperatures, temperature fluctuations, and other climate-related changes (Kingsolver et al. 2011). However, few data exist on these factors for insects in general and most studies have focused on agricultural pests and pollinators (DeLucia et al. 2012), so it is difficult to extrapolate information for California marshes. Some species may be able to adapt to changes through altered behavior or physiology. In laboratory studies simulating climate change, insects adapted to changed conditions by adjusting their rates of feeding or development (Kingsolver et al. 2009). Invertebrates may also show evolutionary changes to climate change, through selection for particular morphological or physiological traits. Based on global phenology observations of wild plants Wolkivich et al. (2012)

estimates that spring leafing and flowering may advance at the rate of 5-6 days per degree C. These changes in plant phenology may ultimately lead to temporal mismatch with plants and their pollinators (Wolkovich et al. 2012) and insect emergence times with vertebrate consumers (such as juvenile fish, tidal marsh birds, and their young; Dunn et al. 2011).

FACTORS THAT MAY AFFECT SPECIES RESILIENCE

Whether marsh macroinvertebrates can adapt to climate change may depend on how the current climate and other abiotic features of the marsh such as inundation rates and salinity compare to each species' tolerance to those stressors. Deutsch et al. (2008) predicted that temperate insect communities would overall see little to some positive effect from increased temperatures, based on the fact that many of these species are already adapted to seasonal fluctuations and not living at the limit of their environmental tolerance. Of course, individual species could still suffer even if overall insect or other invertebrate populations increase.

Invertebrates' survival, growth, and reproduction depend partly on temperature. Species have a range of temperature tolerance and a smaller range of optimal temperature where growth, reproduction, or survival is maximized. Marsh species also experience variation in water and air temperatures that depend on the tidal cycle, freshwater inputs from riverine systems, and by season. A species' resilience to climate change may depend on where current conditions fall within its range of tolerance or optimal conditions. An additional complication is that while a species may inhabit a large geographic range, such as with *Hemigrapsus oregonensis*, local populations may be adapted to local conditions and their resilience to climate change will depend on how well they can tolerate a new range of variation. Finally, the overall effect of climate change on the marsh macroinvertebrate community will also be influenced by interactions among species, such as relative effects on predators versus their prey (Freitas et al. 2007). We lack data on these questions for species in San Francisco Bay marshes so we cannot make specific predictions.

Invertebrates could use behavior to adapt to climate change. Some species might be able to go into diapause to avoid high temperatures. For some species, such as intertidal snails, increased inundation due to sea level rise could reduce stress from desiccation. Others such as aerial insects may need to move higher on vegetation to avoid extended periods underwater. These are educated guesses and also based on the assumption that a variety of micro habitats will remain in sufficient quantities and quality as the sea level rises.

LIKELY CLIMATE CHANGE IMPACTS AND RISKS

- Habitat loss due to increased sea levels and inability to migrate marsh landward.
- Possible reduced survival of species and changing abundances and distributions as salinities become more variable under future climate change projections.
- Possible reduced survival of species for which increased temperatures are outside their temperature tolerances but fewer effects and possibly even increased populations of species that are not at their upper limit of temperature tolerance.

MANAGEMENT ACTIONS TO BE CONSIDERED

As this group, marsh macroinvertebrates, covers a wide range of organisms, any management action could have positive impacts for some and negative impacts for others. Designing marsh restoration or sea level rise adaptation plans so that future marshes will retain mid- to high marsh elevations and transition zones will help preserve the species and ecosystem functions in the marsh plain. Maintaining or adding connections among marshes, or between marshes and the upland transition zones, would likely benefit many species. See the transition zone chapter for more specific recommendations.

UNCERTAINTY AND KNOWLEDGE GAPS

There is much uncertainty about the effects on tidal marsh macroinvertebrates because they have not been well-studied in California. The magnitude of climate change impacts depends in large part on each species' tolerance to changes in temperature or salinity outside the range of current conditions.

Little is known about tidal marsh macroinvertebrates in California and much less is known about the impacts of climate change on these communities. The effects of climate change on macroinvertebrates in general are uncertain, although laboratory studies have provided some examples of what might occur (Deutsch 2008, Kingsolver 2011). Some research has been done in the course of monitoring the progression of marsh restoration projects (see for example Talley and Levin 1999), food webs for fishes and aquatic systems (Howe and Simenstad 2011, Herbold et al. 2014), and changes in food web dynamics due to invasive *Spartina* (Levin et al. 2006, Brusati and Gorsholz 2009). Perhaps the greatest data gap involves impacts to marsh macroinvertebrate distributions, densities, and community structure due to climate change and other environmental stressors and the resulting food web impacts to their vertebrate consumers.

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