spectrum of climate phenomena. However, spatially and temporally sparse observations prevent us from completing a zero-order description of the Pacific LLWBCs. Thus models play a crucial role in the elucidation of the interplay between changes in LLWBCs structure and large scale climate.

Changes in the dynamics of the Pacific LLWBCs are explored using an intermediate resolution version of the Geophysical Fluid Dynamics Laboratory Modular Ocean Model 3 with an optimal interpolation scheme for assimilation of surface and subsurface temperature data. The model is forced with bias corrected weekly reanalysis winds from the National Center for Environmental Prediction (NCEP). This correction varies spatially, with largest differences in tropics, but does not vary in time. SST is damped to NCEP weekly values and the sea surface salinity is damped to monthly mean climatology from the Comprehensive Ocean Atmosphere Data Set with a damping time scale of 21 days. The model was spun up for 20 years using climatological winds and then run from 1948 to 2000.

In this study we address the question of how the fluctuation of volume, heat transport, and bifurcation latitude of the North Equatorial Current and the South Equatorial Current, the major upper ocean zonal flow suppliers of the Pacific LLWBCs, influence climate on both interannual and decadal time scales. A number of previous studies stress the influence of Northern Hemisphere water anomalies that reach the western boundary due to the presence of the atmospheric Inter-Tropical Convergence Zone which creates a potential vorticity barrier. However, we find that Southern Hemisphere anomalies that reach the western boundary have more impact because those in the Northern Hemisphere weaken relative to the Southern Hemisphere before reaching the western boundary. Additionally, most of the thermocline flow from the south, which contains significant anomalies, retroflects eastward into the Equatorial Undercurrent and the northern Subsurface Countercurrent with an impact on Tropical Pacific climate.

OS11N-11 1135h

Surface water mixing in the Solomon Sea as documented by a high-resolution coral-14C record.

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A bi-monthly coral-based record of the post-bomb radiocarbon content of Solomon Sea surface waters is interpreted to reflect mixing of subtropical surface water and that advected in from the east by the equatorial branch of the South Equatorial Current (SEC). Annual mean D14C has a dynamic range of nearly 175per mil, with a total range of nearly 200per mil. Pre-bomb values average -56per mil and the annual mean post-bomb maxima occurs in 1985 with a value of +117per mil. Interannual variability in the record reflects surface current variations in conjunction with surface wind changes associated with ENSO. During El Nino years the waters of the Solomon Sea reflect a stronger influence of waters advected in from the east by the SEC and less "pure" subtropical water. This is most likely accomplished by a southward shift of the SEC during El Nino. There is an overall decrease in the relative proportion of eastern tropical water which could be interpretted to reflect a decrease in the strength and intensity of upwelling in the eastern Pacific. Our observation of decreasing upwelling tends to support the contention that there is a bias in the observed wind field products.

OS11N-12 1150h

The Indian Ocean STC from the SODA model and observations

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From observations of western boundary cross-equatorial flow by the Somali Current, from upwelling off Somalia and Arabia and from southward Ekman return flow the intensity of the cross-equatorial shallow thermohaline cell of the Indian Ocean is estimated at about 7Sv. These observations are compared with the output of the Simple Ocean Data Assimilation (SODA) model of Carton et al. (2000), which is based on assimilations of SST and T/P altimetry. Estimates of subduction in the southern hemisphere and upwelling in the northern hemisphere, as well as transport sections are studied to discuss sources, pathways and sinks of the Indian Ocean STC and its interannual variations.

OS11O HC: 316 C Monday 0830h

Coupled Biophysical Processes, Fisheries Resources, and Climate Variability in Coastal Ecosystems of the Northeast Pacific Ocean I

Presiding: **F B Schwing,** Pacific Fisheries Environmental Laboratory; **S E Allen,** Dept. of Earth and Ocean Sciences, University of British Columbia

OS11O-01 0830h

Mixed Layer Depth Variability on Decadal and Interdecadal Scales in the Northern Gulf of Alaska

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The mixed layer depth (MLD) in the North Pacific controls the vertical flux of nutrients into the euphotic zone and hence affects the biological productivity there. A time series of hydrographic measurements, temperature and salinity versus depth, at a coastal site in the northern Gulf of Alaska is used to determine the seasonal and interannual variations of the MLD from 1974 through 1998. This station, GAK 1 (59°50.7'N, 149°28.0'W), is in 263 m of water. Seasonal and interannual variations of the GAK 1 temperatures and salinities reveal 1) a possible coupling between salinity, density and freshwater discharge and 2) a strong coupling between temperature and Pacific Decadal Oscillation (PDO) and the Southern Oscillation Index (SOI). The environmental parameters or physical forcing can be separated according to their dominant periods of variation; 1) seasonal, 2) El-Niño – Southern (ENSO) periods of less than 10 years or 3) decadal periods. The hydrographic parameters primarily have seasonal variations. However, they also have ENSO periods, though the deep waters, in addition, have significant interdecadal variations. The upwelling index has seasonal variability and approximately equal contributions from ENSO and interdecadal variability, while freshwater discharge variations have seasonal, ENSO and decadal periods.

The MLD changes seasonally from about 50 m in summer to more than 130 m in winter. These changes are in response to the seasonal variations in the wind stress, solar heating, precipitation, and freshwater discharge. The 25 years of hydrographic data also allow the determination of interannual variations in this MLD. The MLD trend over this period is for a slight increase in the MLD that is not statistically significant. This is in contrast to previous studies which found a significant shoaling of the MLD in the central region of the Gulf of Alaska (Ocean Station P, 50°N, 145°W). This difference in the response of the marine system is consistent with an increase in the circulation of the Alaskan Gyre with enhanced upwelling in the central gulf (Ocean Station P) and enhanced downwelling along the coast (GAK 1).

OS11O-02 0845h

Trends and Change Points in the Subsurface Temperatures of the California Current System

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State-space models are used to examine long-term trends, nonorthogonal common trends, and significant climate-driven change points in a set of subsurface temperature time series representing the meridional and offshore extent of the California Current System (CCS). We use global one-degree summaries from the World Ocean Database at 11 locations and 10 standard depths in the upper 200 m for the period 1948-94. Four common trends account for most of the total variance and the important time-dependent features of the temperature series. The first common trend, essentially a weighted mean of the series, reveals a series-long warming tendency at all locations, with the greatest changes occurring at 50 m (75 m) depth for the coastal (offshore) stations. Superimposed on the long-term warming trend are a number of interannual fluctuations, most associated with El Niño and La Niña events. Weights for the second and third common trends clearly separate the study area in the offshore and meridional directions, respectively, while the fourth common trend separates the series by depth. Many of the features and change points described by the first common trend are also seen in the second common trend, but accentuated at coastal locations and mitigated offshore. In particular, the rapid warming seen around the 1976 regime shift in the first common trend appears to be an acceleration of a warming trend that began several years earlier. The third common trend, with weights greatest in the thermocline, features maxima during strong El Niño years, thus accentuating these events at southern latitudes (and in the thermocline) but neutralizing their signal north of 40°N. The depth-dependent effect of the fourth common trend reveals a gradual warming of the thermocline prior to 1983 followed by a cooling trend, leading to increased thermal stratification in the CCS. We use these results to speculate on the nature and causes of regime shifts and variable ENSO responses in the Northeast Pacific, and on their biological consequences.

MON

OS11O-03 0900h INVITED

Decadal Regime Shifts in the North Pacific: Physical Mechanisms and Ecological Consequences

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In recent years, researchers trying to document and understand the impacts of climate variability on north Pacific marine ecosystems have witnessed exceptional environmental extremes. One of the strongest El Niño events on record, in 1996-97, was followed by a strong La Niña in 1998. The transition between these events was by many measures the most dramatic and rapid episode of climate change in modern times. For example, ocean temperatures off central California fell by nearly 10°C in less than two years. Within the context of these El Niño and La Niña events, a longer-term climate shift in late 1998 or early 1999 produced striking anomalies in environmental conditions. Many of the atmospheric and oceanic anomalies that developed at this time have remained to the present. These also bear strong resemblance to anomaly patterns associated with previous decadal-scale climate regimes (e.g., before 1976). This new physical state seems to have translated into substantial alterations in marine populations at all trophic levels. As with many oceanic changes, reports of shifts in living marine resources first drew attention to this period as a regime shift. Atmospheric and oceanic anomalies prior to and during this regime shift will be described, with an eye toward how this particular period might be similar to, or differ from, previous documented regime shifts, as well as major El Niño and La Niña events. Possible mechanisms responsible for this shift, and their geographic sources, will be discussed. Another focus will be on biological changes observed in the north Pacific in 1998 that may be related to this regime shift. At a minimum, we have learned that marine ecosystems can respond to environmental change in a surprisingly swift and dramatic way.

OS11O-04 0925h

Climate Variations in the Northeast Pacific: Dynamic Similarities and Links to the Northwest Atlantic

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The northeast Pacific (NEP) undergoes a wide range of climate variations, including intraseasonal to decadal events. These events may have major impacts on basin to local scales. Sorting out the mechanisms that create these events and their interactions with each other is a complex problem. However, applying dynamic similarity concepts can make the problem much simpler. In our studies we have found several major similarities in the processes that operate over a wide range of time and space scales. The similarities in atmospheric teleconnection and air-sea forcing processes are especially pronounced. We present several examples of these processes and their impacts on the NEP at intraseasonal, interannual, and decadal scales. We also examine how climate variations in the NEP are linked to those occurring in Asia, North America, and the North Atlantic. A number of past climate events in the two U.S. GLOBEC regions, the NEP and the northwest Atlantic, have similar origins. Increased understanding of the mechanisms of climate variations in the GLOBEC regions should lead to improved monitoring and, eventually improved predictions, of these changes.

OS11O-05 0940h

Equilibrium Physical and Ecosystem Dynamics of the California Current System

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Our research addresses the structure and mechanisms of regional and meso-scale, physical and biological variability in the west coast of the United States. The principal tool is a newly developed simulation model for ocean circulation and ecosystem dynamics. It is configured in east-coastal domains that span the California Current System (CCS), with meso-scale resolution that currently is as fine as 3 km. The equilibrium solutions of the physical model show realistic mean seasonal states and vigorous mesoscale eddies, fronts, and filaments. The biological model is adapted from Fasham et al. (1990) with differences due to the nature of coastal upwelling. In our solutions, the phytoplankton distributions are tightly coupled to the upwelling and filamentary physical structure, and are similar to the pattern and scales of observed chlorophyll distributions. Our objective is to use the model solutions to diagnose how physical transport and ecosystem dynamics control plankton distributions in the CCS. A troubling aspect of these simulations is the sensitivity of coastal upwelling and even the large-scale circulation (especially the Davidson Current whose role on the migration of juvenile fish is yet to be fully determined) to uncertainties in the large-scale, low-frequency wind analyses used to force the model. Secondly, our simulations may be near a resolution threshold with respect to near-shore, small-scale, ageostrophic instabilities, which are shown to be potentially significant for both physical and plankton dynamics.

OS11O-06 0955h

Coastal Upwelling Response to Atmospheric Wind Forcing along the Pacific Coast of the United States.

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Wind stress is recognized as the most important driving force for coastal upwelling. Along the West Coast of the United States, although wind stress is mainly directed towards the equator, i.e. favorable to upwelling, it shows important spatial and temporal variations.

A model of the Central California Upwelling System has been developed to assess the ocean response to different wind forcings. A nesting capability has been integrated into the Regional Ocean Modeling System (ROMS) to obtain local solutions at high resolution while preserving the large-scale circulation at affordable computational cost. It has been applied to a domain that covers the central upwelling region of the United States West Coast, around Monterey Bay, embedded into a domain including the whole US Pacific Coast. Long term simulations (10 years) have been conducted to get yearly cyclic statistical equilibria.

Several simulations are performed, forced by different monthly mean wind stress climatologies: COADS, NCEP, QuickSCAT and COAMPS. The spatial sampling of these data-sets ranges from more than 100 kilometers for COADS and NCEP to 9 kilometers for COAMPS. While on the large scale these winds are relatively similar, they show important variations in the Coastal Transition Zone. In particular, COAMPS winds present strong and narrow gradients in the near-shore region which are not resolved by the other products. The model experiments show large sensitivities of coastal upwelling and even large-scale circulation to the spatial structure of the wind forcing at intermediate scales (tens to hundreds of kilometers).

OS11O-07 1030h

On the Need for Simulations of Coastal Ocean Physics and Ecosystems (SCOPE)

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The California Current System and the coast of California in particular have been the focus of many time series and process studies. The region is among the most studied in the world yet many important questions remain unanswered. The region is subject to strong interannual and longer-term climate variations raising further questions about how it will respond to the predicted rise in temperature associated with increasing greenhouse gases in the atmosphere. The rich historical data-base and excellent matrix of real-time ocean observing systems available in the California coastal upwelling system and the set of important scientific questions have led us to pursue the development of the next generation of coupled coastal physical-biological models. A high-resolution coastal model has or will be nested within regional and basin-scale models. The model includes the interconnected physical, chemical, and biological processes, and will be capable of assimilating data from satellites and in-situ sensors. The model focus is on simulating the observed seasonal and interannual variations in physical oceanographic forcing and the chemical and biological consequences. In this presentation we review our current understanding of processes at work in the California coastal upwelling system and their scales of variability. We then describe briefly our modeling approach and highlight a few of the challenges to date. We argue that many of the important scientific questions need to be investigated with these coupled models. The details of our progress, from atmospheric forcing issues to ecosystem modeling, can be found in a series of companion presentations.

URL: http://www.mbari.org/NOPP

OS11O-08 1045h

Modeling the Mean Circulation and Seasonal Cycle of Monterey Bay, California

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Ocean circulation and variability in the Monterey Bay (MB), California, has recently received considerable attention. In 1989, the Monterey Bay Aquarium Research Institute (MBARI) installed a number of moorings in central MB and initiated frequent time series cruises both within and offshore of MB. MB is probably the most extensively monitored non-estuarine embayment that is broadly open to the coastal ocean. Thus, the MB provides an ideal location to develop a sophisticated 3-dimensional model for coastal oceans.

Our modeling goal is to develop a high-resolution physical model for the MB region that is capable of reproducing both the mean MB circulation and the seasonal-to-interannual variability. The physical model is based on the Regional Ocean Modeling System (ROMS), which is a terrain-following vertical coordinate model and solves the hydrostatic primitive equations in three-dimensional curvilinear coordinates. Our initial model domain covers the MB with approximately 1000 km along shore and 500 km offshore. The horizontal resolution is approximately 5 km, and there are 20 sigma layers. Open boundary conditions are applied with prescribed temperature and salinity observations. The baseline atmospheric forcing is derived from the Comprehensive Ocean-Atmosphere Data Set (COADS), including the wind stress, heat and fresh-water fluxes. Starting from the observed temperature and salinity, the 5-km MB ROMS is integrated for ten years forced with the monthly climatological air-sea fluxes. The last five years' simulation is used to define the climatological MB mean circulation and the seasonal cycle.

Systematic model and data intercomparisons are conducted with an aim to quantify the success and deficiencies of the MB ROMS. The observational data sets include both surface observations (sea surface temperature and sea level) and vertical cross-sections (CalCOFI Line 67 and MBARI moorings at C1, M1, and M2). One of our major findings is the inadequacy of the COADS wind stress, which is gridded at 100-km spatial resolution and suitable primarily for large-scale models. The impact of a high-resolution (approximately 25-km) satellite scatterometer wind product (from the QuikSCAT mission) on the MB ROMS simulation will be presented.

OS11O-09 1100h INVITED

Upper trophic level surprises off B.C. during the 1990s and their physical and biological drivers: Global warming in action?

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During the 1990s, atypical species distributions, changes in community composition, and changes in survival were observed for many high trophic level fishes and seabirds off the west coast of British Columbia. These include changes in the growth and survival of seabird chicks, increased abundances of warm water pelagic fishes such as Pacific hake, sardine and chub mackerel, and decreases in the populations of cold water pelagic fishes such as several species of salmon. Much of the 1990s were unusually warm off BC, which ended rather abruptly in 1999 with a return to conditions typical of the 1960s and early 1970s. We provide a synthesis of Canadian GLOBEC studies off the west coast of Canada during the 1990s and examine in detail the physical and biological oceanographic changes and their consequences for higher trophic levels. We also examine whether these oceanographic changes are consistent with a period of extended El Niño events, whether the biological changes simply represent latitudinal shifts in zoogeographic distributions, or whether they may provide a glimpse into the potential marine ecosystem changes in the NE Pacific that may result from continued global warming.

OS11O-10 1125h

Responses of California Current populations to environmental variability

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Fishery and environmental data indicate California Current Dungeness crab chinook salmon and coho salmon populations respond to common forcing by a California Current Index which is the first EOF of ocean temperature, sea level and upwelling index, and represents warm/cool ocean conditions. However, these populations respond to the environment in different ways. Coho salmon varied synchronously along the coast on a one year time scale, and collapsed in the mid-1970s. Chinook salmon varied with a spatial pattern, on 3-5 year time scales, and did not collapse. With a model of single population dynamics, we show that a common explanation for these differences, greater variability in spawning age in chinook salmon, does not hold. With a metapopulation model with straying among populations we show that a small amount of straying can reduce the propensity for population decline. However, there is not a demonstrated difference in straying between these species. We conclude that it is likely that the difference in response is due to some other, biophysical interaction.

OS11O-11 1140h

Variability of One-Dimensional Mixing Processes on the Southeast Bering Sea Shelf

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A seven-year time series of current velocities, temperature, salinity, and fluorescence (among other variables) has been obtained from a mooring on the southeast Bering Sea shelf. During the summer, currents are weak in this area, suggesting that the primary stratification/mixing processes are one-dimensional. Using the mooring data, a mixed layer model has been tuned to represent the physical environment of the region as accurately as possible. During the seven years for which we have data, the mixed layer model reproduces the observed temperature structure, heat content, and timing of mixing events during the summer months amazingly well, confirming the one-dimensionality of the system.

Using NCEP Reanalysis sea surface temperature to initialize the model each spring, and windstress and heat fluxes to force the model, a series of summer model runs is executed covering the period from 1948 to the present. This period includes the regime shift of the mid-1970s allowing examination of the physical environment in this region during the two different regimes.

As the surface warms due to increasing solar radiation in early spring, the resulting stratification allows for an early spring phytoplankton bloom. Subsequently, the surface water becomes nutrient depleted such that further mixing events are necessary for further primary productivity. As these mixing/stratification processes are important to the ecology of the region, a better understanding of the variability in the physical environment and mixing processes is needed. Using the model output since 1948, variability of the physical environment over the last 50+ years on interannual to decadal timescales will be discussed.

OS11P HC: 314 Monday 0830h

Interactions Between Macro- and Microorganisms in Aquatic Sediments I

Presiding: **E Kristensen,** Odense University; **J Kostka,** Florida State University

OS11P-01 0830h INVITED

Interactions Between Macro- and Micro-organisms in Sediments: The Role of Density-dependence

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Ecologists have long recognized that interactions among organisms, and community dynamics, shift dramatically when organisms reach critical densities. Such nonlinearities form the basis for the examination of complex interactions in ecosystems and frequently involve the study of processes occurring over multiple spatial and temporal scales. In sedimentary environments, interactions among macro-organisms and microbes are likely to be similarly influenced. To date, there is ample evidence that critical densities of macroorganisms, or their structures, impact the fluid dynamic environment and influence benthic boundary layer processes. However, the effects of organism density on surface chemistry or subsurface processes are less explored, from an experimental or theoretical point of view. There are few experiments that specifically test the effects of macro-organism density on rates and fluxes of geochemical properties, and at the same time, characterize the feedback of these interactions on ecological processes in sediments. Yet there is ample evidence to suggest that these processes have significant implications for biogeochemistry. Our current modelling approaches also do not reflect the realities of community structure. In general, concentration-based models address the "average environment", perhaps reflecting the activities of one or more organisms without considering how the density of these organisms may change the emergent properties of the habitat. Individual-based models can include such characteristics but are limited in the number of processes they can consider, or the areal extent of consideration, due to computational intensivity. Examples of density dependent processes and feedbacks between macro-organisms and sediments will be discussed and new data concerning the effects of infaunal density on surface and subsurface geochemical processes will be presented. The relationship between density dependence, reaction kinetics and primary productivity will be explored.

OS11P-02 0900h

Effects of Macrophytes and Macrofauna on Saltmarsh Pore Water Redox Chemistry (Sapelo Island, GA, USA)

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The redox geochemistry of saltmarsh sediments is influenced by factors such as tidal flushing, microbial activity, bioturbation and the presence of vegetation. This leads to distinct spatial trends in redox conditions, which are assessed here at an unvegetated tidal creek bank, a densely vegetated levee and a sparsely vegetated ponded marsh. At the ponded marsh, vertical pore water profiles measured from the surface to 50cm define a depth sequence of oxic, suboxic, sulfidic and, sometimes, methanic zones. At the creek bank, only oxic and suboxic zones are observed. Redox zonation at the levee site is intermediate, with oxic and suboxic zones, and, in some seasons, a sulfidic zone.

The influence of burrowing macrofauna on pore water geochemistry is assessed here using a new 3D stochastic burrow network model. Burrow networks are constructed using probability distributions derived from ecological data describing burrow sizes, shapes and densities for polychaete worms, fiddler and mud crabs and shrimps. Mean densities and wall surface areas of burrows, and their variabilities with depth, are extracted from the networks. Nonlocal bioirrigation coefficients are calculated from burrow surface areas and the characteristic reactive length scale across the burrow-sediment interface, which is estimated from measured sulfate reduction rate profiles (Kostka et al., 2001, Biogeochem., in press). Bioirrigation intensity is highest and deepest at the creek bank site and lowest and shallowest at the ponded marsh site.

S. alterniflora roots are capable of pumping O2 into the surrounding sediment (Lee et al., 1999, L&O 44, 1155). However, macrophytes also increase sediment organic matter content by increasing primary productivity and releasing root exudates, or by trapping organic-rich detrital material, which is subsequently mixed into the sediment via bioturbation. The influence of macrophytes on pore water redox geochemistry is assessed here using measurements of pore water solutes at two sites, separated by 1.5m, located on the edge of a tidal creek. One site is entirely unvegetated, and the other is being actively colonized by S. alterniflora. Pore water Mn(II), Fe(II), and sulfide concentrations are considerably higher at the vegetated site. Because reoxygenation reactions produce protons, significant root release of O2 should result in decreased pH at the vegetated site. However, pH profiles measured at the two sites are quite similar. This suggests that the addition of organic matter in vegetated zones stimulates anaerobic respiration to such a great extent that the effects of O2 introduced by roots remain localized to the sediment immediately adjacent to the roots.

This study demonstrates that macrofauna and macrophytes are primary causes of spatial gradients in pore water redox chemistry observed at the Sapelo Island saltmarsh. At an unvegetated creek bank, intense, deep irrigation leads to extensive reoxidation of reduced solutes. This, together with less labile organic carbon input than at vegetated sites, creates relatively deep oxic and suboxic pore water zones. At a ponded marsh site, less intense, shallower irrigation, together with labile organic carbon input from S. alterniflora creates more compressed redox stratification, with oxic, suboxic, sulfidic and even methanic zones present in the upper 50cm. Redox conditions at a levee site are intermediate because organic carbon is supplied via dense stands of S. alterniflora, yet intense, relatively deep bioirrigation leads to extensive reoxidation of reduced solutes.

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Elucidating the Effects of Macrofauna vs. Macrophytes on Sediment Biogeochemistry in the Georgia Saltmarsh

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Previous studies have shown that macroorganisms stimulate the rates and pathways of anaerobic microbial respiration coupled to organic matter mineralization in saltmarsh sediments. However, the complexity of biogeochemical cycles in the marsh has so far obscured our interpretation of the mechanisms by which various macroorganisms control predominating diagenetic reactions. In this study, we sampled the top 10 cm depth of four sites exposed to a similar hydrologic regime which differed according to the abundance of dominant macrophyte plants (Spartina alterniflora) and invertebrate macrofauna (Uca pugnax). Sediment geochemistry, counts of anaerobic bacteria, and rates of microbial metabolism were monitored at each of the four sites. Using a most probable number (MPN) approach, counts of sulfate-reducing bacteria (SRB) displayed a range of 5 orders of magnitude and were higher at nonbioturbated as compared to bioturbated sites. In contrast, counts of Fe(III)-reducing bacteria (FeRB) were an average of 1 order of magnitude higher at bioturbated sites. The root zone appeared to influence both SRB and FeRB, as counts increased with sediment depth at vegetated sites whereas they decreased with depth in the absence of vegetation. Molybdate, a specific inhibitor of sulfate reduction, inhibited 50 to 70 percent of carbon oxidation when added to sediment incubations from nonbioturbated sites, whereas only 7 to 26 percent of carbon oxidation was inhibited by molybdate in incubations from bioturbated sites. Sulfate reduction rates (SRR) measured in intact cores were generally higher at vegetated sites, especially below 5 cm depth, whereas a depression in rates was observed at 0 to 5 cm depth at bioturbated sites. The impacts of macroorganisms were also examined through profiling of particle-reactive radionuclides (Be-7 and