The Role of Microbes in Salt Marshes and their Restoration

The interaction between the physio-chemical environment and the organisms present in the ecosystem determine the functioning of an ecosystem; therefore, much effort has been placed on understanding the role of biodiversity in ecosystem functioning. Biodiversity and ecosystem functioning (BEF) have an intimate relationship, as evidence has shown that a decrease in biodiversity can reduce the function of an ecosystem and the services that that ecosystem provides (Finlay et al., 1997, Worm et al., 2006). We speak on diversity in the macro world, often citing "all" of the organisms in the rainforest. However, the diversity of those unseen by the naked eye can far outnumber those we can see, especially considering that bacterial cells outnumber our own at an underestimate of 10 to 1 (Turnbaugh et al., 2007). A microbe is a simplified term for a large group of single-celled organism, including prokaryotes (Bacteria and Archaea), fungi, and protists. Although they play a significant role in ecosystem function, the effect of diversity of microbes is still largely unknown. From the handful of laboratory and field experiment conducted thus far, we have concluded that greater microbial diversity can contribute to processes in the ecosystem in multiple ways, including an increase in the utilization of organics and nutrients and a greater reaction time in state changes (Danovaro and Pusceddu, 2007). Yet there are instances when the microbial diversity in an ecosystem may not matter, as long as the dominant microbes are providing their service (Moseman-Valtierra et al., 2010). As physical and chemical factors of the environment are directly related to ecosystem functioning and microbial activity is responsible for a great deal of physical and chemical parameters, it seem that microbes are, by association, directly related to and inseparable from ecosystem functioning (Finlay et al., 1997). Microbes are responsible for critical processes within salt marshes, including actively decomposing organic matter, acting in synergetic relationships with marsh plants, and playing a vital role in many nutrient cycling processes.

Microbe populations, abundances, and diversity are rapidly altered with changes in conditions and quality of the ecosystem. High levels of primary productivity and biogeochemical cycling characterize coastal ecosystems, particularly salt marshes, and microbial communities play an important role in these processes. Microbes within an environment occupy many niches and the changes of environmental conditions within an ecosystem result in an alteration of these niches that are quickly filled by microbes (Finlay et al., 1997). There are always microbes "waiting" for their optimal conditions to be met so that they may proliferate for the short amount of time. Once these organisms deplete their resources or the extracellular environment is altered, new microbes quickly replace them. This turnover of microbial niches is their contribution to ecosystem function, and it is an important one.

Nutrient loading by human inputs results in the eutrophication (i.e. increase in the rate of supply of organic matter) of these systems (Nixon, 1995). Microbes present in the sediments play a key role in removal of anthropogenic nitrogen pollution. Microbes are capable of removing a large percent of this nutrient pollution via the dominant process of nitrate reduction known as denitrification (Hopkinson and Giblin, 2008, Seitzinger et al., 2006). Denitrification is the process of converting nitrate (NO_3^-) incrementally to dinitrogen gas (N_2) that can be permanently removed from the system.

$$\mathrm{NO_3^-} \rightarrow \mathrm{NO_2^-} \rightarrow \mathrm{NO} \rightarrow \mathrm{N_2O} \rightarrow \mathrm{N_2}$$

Unregulated growth of nitrogen inputs can greatly increase the productivity in the system, and even result in eutrophication. Eutrophication can lead to coastal hypoxic zones when the algal biomass decomposes, respiring all of the oxygen in the water column partially or completely and can have negative, cascading effects on the trophic system. This ultimately results in a reduction of biodiversity in addition to zones of hypoxia/anoxia (Kemp et al., 2005). As a buffer between terrestrial and marine ecosystems, it is important to remediate as much anthropogenic nitrogen as possible. Denitrification rates on the marsh platform can increase when inundated with nitrogen, contributing to denitrification in the rhizosphere are the most important in daily nitrogen removal (Koop-Jakobsen and Giblin, 2010). There clearly needs to be a delicate balance between the retention and removal of nitrogen in coastal ecosystems.

This process of denitrification and its response to eutrophication stresses the importance of plant-microbe interactions in salt marshes. Microbes are also entirely responsible for other processes in the nitrogen cycle, including those that fix nitrogen in the soils. Nitrogen fixation converts N_2 gas into a reactive form of nitrogen, ammonia/ammonium, which can be taken up by marsh plants.

$$N_2 + 8H^+ + 8e^- \rightarrow 2\,NH_3 + H_2$$

Marsh plants play a major role in salt marsh functioning by acting as a sink for atmospheric carbon (Duarte et al., 2005). There is evidence to support that the plant communities themselves have a direct relationship with the microbial community assemblages in their rhizosphere (Burke et al., 2002, Hamilton and Frank, 2001, Zak et al., 2003), and like microbial communities, they are controlled largely due to physio-chemical factors.

Environmental stressors, for instance, include high salinity, which correlates with high concentrations of sulfate and hydrogen sulfide, and low oxygen availability (Bagwell et al., 1998). Chemistry in the soil and porewater also affect the growth and productivity of marsh plants. These stressors may also select for different microbial community compositions and diversity. The flux of carbon throughout ecosystem are dominated by microbes as they are the dominant source of primary production and respiration (Duarte and Cebrián, 1996). The symbiotic interaction between microbes and plants to increase productivity plays into the ecosystem service provided by marshes in acting as a net sink of atmospheric carbon.

Although nitrogen is a hot nutrient-of-study in many ecosystems, microbes are responsible for the cycling of other nutrients (C, H, O, and S in addition to N) that are essential to life. Salt marsh metabolism relies heavily on sulfur with its role in the accepting, donating, and carrying of electrons through the ecosystem, especially in sulfur reduction and respiration (Howarth and Giblin, 1983, Howarth, 1984). Salinity is a major driver in the distribution of microbial communities and their diversity (Lozupone and Knight, 2007). Salinity also positively correlates with levels of hydrogen sulfide (a reduced form of sulfur) present within the marsh (Bagwell et al., 1998). Chemolithoautotrophic sulfur oxidizers found in salt marshes can oxidize the reduced sulfur and the energy can be used to fix CO_2 from the atmosphere while also building new organic biomass for movement up the trophic levels.

What grows up must also die down. When macrophytes senesce they leave behind their tissue for herbivory and decomposition. The easily consumed, or labile, components are taken by herbivores found within the ecosystem. However, due to the high refractory nature of macrophytes, this isn't enough to break down the organic matter. Microbes are responsible for a great deal of the further fractionation and processing of the fragments left behind by consumers, which can then move up trophic levels or can return CO_2 to the atmosphere via microbial respiration (Zak et al., 2003). The organic carbon left behind by the dead macrophytic tissue can also be used by methanogens, a group of Archaea responsible for the reduction of CO_2 or some other carbon-containing compounds to methane (CH_4).

Marsh restoration, or any alterations of a salt marsh, will alter the microbial community assemblages that have been established. Short-term changes in microbial communities will likely result in a decrease in their ecosystem services, as they are not at optimal growth conditions. As time passes new microbial communities will form that will be more efficient at performing a certain function. Once hydrology, soil geochemistry, vegetation/animals is restored or reaches a steady state then microbial communities will reach a stable state. Although it is difficult to predict the shifts that occur in microbial communities, the presence of microbes in salt marsh ecosystems is important in their function and recovery as an ecosystem. Microbes provide essential services to ecosystems in the form of decomposition of organic compounds, microbe-plant interactions, and reign over the major biogeochemical cycles. Further advances need to be made in determining the role of microbial diversity in ecosystem function, and to elucidate the response of ecosystems changes in biodiversity at the micro-scale. It is necessary to create a system that meets the optimal conditions for microbial growth and production in the hopes of restoring salt marshes so that they can provide their imperative service to the ecosystem.

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