

# Ecological functioning of mangroves under changing climatic conditions

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## Abstract

Mangrove ecosystems are subject to a range of climate change factors, including atmospheric CO<sub>2</sub>, air and sea temperatures, precipitation, and sea-level. This presentation will review key processes whereby these external drivers may influence mangrove ecosystems. Examples from select geographic locations will be used to illustrate ways in which these drivers of change might affect mangrove structure and function.

*Atmospheric CO<sub>2</sub>*: Atmospheric concentrations of carbon dioxide (CO<sub>2</sub>) have increased from 280 ppm in pre-industrial times to 390 ppm today and are predicted to double sometime during the 21<sup>st</sup> century (Solomon et al. 2007). Increases in CO<sub>2</sub> concentration may alter the structure and function of mangroves, both within existing forests at tropical latitudes as well as in mixed communities where mangrove distribution overlaps with that of salt marsh at subtropical latitudes. CO<sub>2</sub> has a direct fertilization effect on plants by enhancing net photosynthesis and improving water use efficiency (Bazzaz 1990; Urban 2003). As CO<sub>2</sub> concentrations increase, CO<sub>2</sub> assimilation rates increase due to greater carboxylation efficiency of Rubisco, the enzyme that catalyzes the initial fixation of CO<sub>2</sub>. At higher concentrations of CO<sub>2</sub>, plants also decrease stomatal openings, thereby reducing loss of water. For C-3 species, the rate of CO<sub>2</sub> assimilation is increased up to a saturation concentration of about 1000 ppm CO<sub>2</sub>. C-4 species are typically less responsive to elevated CO<sub>2</sub> concentration because they already possess a CO<sub>2</sub>-concentrating mechanism at the site of assimilation. Most mangroves are C-3 species and are potentially responsive to elevated CO<sub>2</sub>. Relatively few studies, however, have examined how mangroves respond to higher than ambient CO<sub>2</sub> concentration (Ball and Munns 1992; Farnsworth et al. 1996; Ball et al. 1997; McKee and Rooth 2008). Even fewer studies have investigated how other factors such as competition may modify species responses to CO<sub>2</sub>. A change in the relative competitive ability of mangrove species may influence future range distributions at global, regional, and local scales. One study examined elevated CO<sub>2</sub> effects on the black mangrove, *Avicennia germinans*, which occurs at its northernmost limit in the Mississippi River Delta, USA. Seedlings of *A. germinans* responded to higher CO<sub>2</sub> with increased growth when grown alone, but its growth was strongly suppressed when grown in mixture with the C-4 grass, *Spartina alterniflora* (McKee and Rooth 2008). Elevated CO<sub>2</sub> thus had no detectable effect on *A. germinans* when grown in combination with a strong competitor for nitrogen. Fertilization with nitrogen altered tissue chemistry of mangrove seedlings transplanted to the field and led to higher mortality due to crab herbivory (McKee and Rooth 2008). These findings suggest that biological interactions such as competition and herbivory could modify the potential effects of higher CO<sub>2</sub> on *A. germinans* in this particular setting. Predictions of effects of atmospheric CO<sub>2</sub> on mangroves at a global scale, however, are difficult to make due to limited data. Because such studies are technically challenging and expensive, predictions about future response to rising CO<sub>2</sub> will likely depend on modeling approaches. However, it's clear, based on the work conducted so far, that models predicting an increase in abundance of C-3 mangroves in mixed communities are too simplistic. Factors such as

competition and herbivory, as well as environmental stress factors such as flooding and salinity, must be understood and incorporated to develop more complex models.

*Climate Change:* Global temperature has risen almost 1 °C in this century and is projected to increase from 1.1 to 6.4 °C in the 21<sup>st</sup> century (Solomon et al. 2007). Global warming will pose many threats and benefits for mangrove ecosystems (Saint-Paul, 2012; Bosire et al. 2012; Record et al. 2012). Warmer temperatures will extend the latitudinal range of mangroves, which are restricted to the tropics and subtropics (Di Nitto et al. 2012). Mangroves already appear to be expanding their range, such as on the Atlantic US coast (Zomlefer et al. 2006) and the east coast of Australia (Wilson 2009), and this expansion corresponds to the poleward extension of temperature zones during recent decades (Hennessey et al. 2004). Latitudinal expansion, however, may be inhibited by barriers to dispersal in some locations, e.g., *A. marina* in Australia and New Zealand (de Lange and de Lange 1994). Changes in temperature may also influence mangrove productivity and phenology, especially at subtropical latitudes. Higher temperatures can alter the photosynthetic efficiency of mangroves, improving it in colder climates but causing declines in net CO<sub>2</sub> assimilation in warmer climates as leaf temperatures exceed an optimum level (Cheeseman 2004; Okimoto et al. 2007). The timing of leaf emergence and success of reproduction may also change with climate warming (Gilman et al. 2008), but this may depend on species-specific characteristics (Wilson 2009). Mangrove physiology and phenology will also be affected by changes in precipitation patterns driven by global warming. Climate models predict increased precipitation at equatorial latitudes, but decreased precipitation at subtropical latitudes, with more frequent summer droughts (Solomon et al. 2007). Extreme events, such as droughts, are likely to have a much greater effect on mangroves than gradual changes in average conditions. Such has been the case in the Mississippi River Delta, USA, where a combination of drought, low sea level, and low river outflow led to wide-spread dieback of the salt marsh dominant, *S. alterniflora* in 2000 (McKee et al. 2004). More drought-tolerant species, such as *A. germinans* and *J. roemerianus* (black needlerush) were unaffected. This event, and the absence of killing freezes during this same time interval, created opportunities for rapid expansion of *A. germinans*. In this case, the extreme weather event was beneficial for mangrove expansion, but this outcome may not be the case for other mangrove species with different physiologies and sensitivities to drought, hypersalinity, and other stressful conditions associated with a decrease in precipitation. Those mangroves predominating in high rainfall environments may be negatively affected by climate extremes that reduce freshwater input and increase salinity, e.g., Micronesia (Drexler and Ewel 2001; Krauss et al. 2007). Mangroves may be particularly vulnerable to climate change in areas where human activities have modified freshwater inflow or tidal exchange.

*Rising Sea-Level:* Habitat stability of mangroves in relation to sea-level rise is dependent in part on a feedback relationship between hydro-edaphic conditions and the plant community. Tides, currents, and storms transport sediment that contributes to soil elevations through surface accretion. Rates of mineral sedimentation may be altered as sea-level rise accelerates and storm intensity and frequency increase under global warming. Rising sea level also alters flooding and salinity regimes, which in turn influence plant production and decomposition of organic matter. Water movement brings in nutrients and flushes out phytotoxins, actions that influence the productivity of the plant community. Primary producers trap sediment and contribute directly to soil volume through accumulation of organic matter. The atmospheric concentration of CO<sub>2</sub> is the underlying driver of global warming and sea-level rise, but has a direct fertilization effect on plants, as discussed above. The feedback relationship between

biotic and abiotic components allows the system to self-adjust soil elevations to prevailing water levels and, consequently, to keep pace with rising sea level (McKee et al. 2007; Krauss et al. 2010; Lovelock et al. 2011; McKee 2011; Khan 2012). If the hydrodynamic setting or other factors affecting production-decomposition processes change, then the ability of the plant community to stabilize the soil and maintain surface elevations relative to water levels will be altered. Historically, the emphasis has been on physical processes such as mineral sedimentation/erosion (Ellison 1993; Parkinson et al. 1994; Cahoon and Lynch 1997; Rogers et al. 2006) or shrink-swell movement due to water flux (Whelan et al. 2005; Rogers and Saintilan 2008) to assess the capacity of mangroves to maintain surface elevations within the intertidal plane. More recent work, however, has shown how biotic processes can directly and indirectly influence elevation dynamics (Cahoon et al. 2003; Krauss et al. 2003; Cahoon et al. 2006; McKee et al. 2007; McKee 2011). Although mineral sedimentation may be affected by vegetation characteristics, biotic processes that contribute directly to soil volume have the greatest potential to influence vertical accretion and elevation change (McKee 2011). These biological processes can be divided into surface and subsurface processes. Surface processes include accumulation of decaying organic matter such as leaf litter or formation of living benthic mats (e.g., microbial, algal, or root matter), which contribute to vertical accretion. Subsurface processes such as root production, root mortality, and decomposition influence soil volume, either contributing to expansion or to subsidence. Although the soil binding capacity of plant roots in coastal systems has been recognized for some time (Scoffin 1970; Spenceley 1977), their role in soil elevation change has only recently been experimentally demonstrated (McKee et al. 2007; Cherry et al. 2009; Langley et al. 2009; McKee 2011). Experimental manipulation of nutrients (nitrogen and phosphorus) in a Belize mangrove forest, for example, altered elevation change rates and patterns through changes in root matter accumulation (McKee et al. 2007). In this mangrove system, subsurface movement indicated expansion where root production was high and subsidence where it was low. Both surface and subsurface land movements must be considered in relation to sea-level trends to assess risk of submergence. In addition, regional variation in sea-level trends and geophysical phenomena must also be included in such assessments. For example, mean sea-level trends based on satellite altimetry shows hotspots with rise rates up to three times higher than the global average, e.g., in the western Pacific (Cazenave and Llovel 2010). A combination of high subsidence and high regional SLR would substantially increase vulnerability of mangroves in such regions. Establishment of a global network of mangrove sites where soil elevation dynamics can be monitored and compared would greatly contribute to a better understanding of how these systems may respond to future sea-level rise (Sharma 2012).

In summary, changes in atmospheric CO<sub>2</sub> concentration, climate, and sea level will lead to complex interactions affecting the structure and function of mangroves (Azad and Matin 2012; Khan 2012). Much of our understanding, however, is based on limited data and observational studies of mangrove flora. Less is known about impacts to fauna and ecosystem-level processes, but changes in the mangrove community will have consequences for dependent fauna as well as for ecosystem functioning. Predicting such effects is problematic, however, since the drivers of change may have contrasting effects on primary production, nutrient cycling, or food-web support. Future progress will be aided by multivariate approaches that allow simultaneous examination of multiple drivers of change along with internal feedback pathways and linkages among physical and biological components.

**Keywords**

coastline, greenhouse gas, intertidal, land building, swamp, vegetation shift, wetland

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