Sandy beach ecosystems and climate change

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Sandy beaches are iconic assets that provide irreplaceable ecosystem services to society. Despite their great socio-economic importance, beaches as ecosystems are severely under-represented in climate change ecology. This is particularly worrying, because recent studies have shown that sandy beach biota are being threatened by several drivers acting at multiple temporal and spatial scales, including fishing, climate, and globalization of markets. Here, we examine whether sandy beach ecosystems have been observed to respond to recent climate change in ways that are consistent with expectations of hypotheses from the general climate-change ecology literature or from predictive models. The assessment, mostly based on recent evidence coming from long-term analyses on beach ecosystems of South America, showed important effects of climate variability on the physical environment and resident biota, with negative socio-economic implications.

The environment

Mirroring global trends, an increase in sea surface temperature anomalies (SSTA) has been observed over the past three decades along the Atlantic coast of South America, including Uruguay. Wind speed anomalies (WSA) also increased through time and were associated with an increasing speed of southerly winds, particularly after 1997. These trends affected the morphodynamics of Uruguayan sandy beaches in a differential way: dissipative beaches showed an increase in swash and beach width, and two composite indices of beach state (Dean's parameter and the Beach Index), together with a decrease in beach slope, augmenting the beach's dissipative characteristics. By contrast, reflective beaches showed an increase in slope and swash width through time, and a decrease in the Beach Index, indicating an intensification of reflective characteristics. Long-term changes were more evident in dissipative beaches and related to climate forcing, even though an increasing frequency of storms is affecting both beach types.

The biota

Observational studies of South American beach invertebrates were used to assess whether recent temporal trends, as synthesized at the continental scale, are consistent with expected responses to climate-change. Two emblematic sandy beach clams of the Genus *Mesodesma* (Antarctic origin and associated with cold water systems) suffered mass mortalities caused by extreme SSTA, particularly at the trailing edge of their ranges. In the Pacific, strong warming pulses associated with ENSO events caused mass mortalities of *M. donacium*, resulting in a poleward contraction of this species' distributional edge. In the Atlantic, mass mortalities of *M. mactroides* sequentially occurred in a north-south direction from 1993 (southern Brazil) to 2002 (Isla del Jabali, Argentina), mainly between late spring and early summer, when these cold-water clams are more sensitive to diseases. None of the affected populations has yet recovered to pre-mass-mortality levels, with greatest mortality effects observed, as expected under climate change, at the trailing range edge. A 30-year study of *M. mactroides* on Uruguayan beaches showed that several biological traits changed consistently with expectations under climate showed that several biological traits changed consistently with expectations under climate change: (1) lower population densities; (2) lower rates of fecundity, recruitment and adult survival; and (3) increased signs of physiological stress (e.g., morphological abnormalities and parasites).

On both the Pacific and Atlantic shores of South America, the composition of sandy beach assemblages changed over recent decades, with species having stronger biogeographic affinities to the tropics increasing in prominence over those of cool-water provenance. Specifically, clams of the genus *Mesodesma* that had dominated the biomass were virtually extirpated at their northern range edges, being at least partially replaced by the clam *Donax* and the mole crab *Emerita*, suggesting "tropicalization" of sandy beach communities. In addition, leading range edges expanded with warming in species with tropical affinities, such as in the ghost crab *Ocypode quadrata*. Recruits of this species occurred with increasing frequency on southern beaches, and might maintain populations there for longer, suggesting a poleward shift in its leading range edge of the population.

Socio-economic implications of climate-driven changes on sandy beach biota

Climatic-driven effects, acting in concert with socio-economic drivers, had immediate repercussions in economic activities, including small-scale fisheries that play a critical role in terms of food security and poverty alleviation in Latin America. For example, increasing WSA in the Uruguayan coast, associated with faster and more frequent onshore winds, explained the linear increasing pattern in swash width through time. These changes in the intertidal habitat negatively affected clams' recruitment and survival, as well as the accessibility by fishers to the resource. Thus, economic income from fishing diminished due to a decrease in the number of fishable days through time.

The major long-term threat facing sandy beaches worldwide is coastal squeeze, which leaves beaches trapped between erosion and rising sea level on the wet side and encroaching development from expanding human populations on land, thus leaving no space for normal sediment dynamics. Sea-level rise and other effects of global warming are expected to intensify other anthropogenic pressures, and could cause unprecedented ecological impacts. The immediate priority is to avoid further development of coastal areas likely to be directly impacted by retreating shorelines. There is also scope for improvement in experimental design to better distinguish natural variability from anthropogenic impacts. In this sense, sandy beach ecosystems have unique attributes (discussed in this presentation) that allow hypotheses to be addressed to quantify the effects of climate change. Multidisciplinary investigation programs and conservation strategies are needed to mitigate negative anthropogenic effects on these ecosystems.