Ecosystems - How do ecosystems and associated services respond to climatic change?

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Ecosystem services, the benefits humans derive from the biodiversity and functioning of ecosystems, provide a direct link between society and the modifications to the biosphere in response to climate change. Examples of services include crop and forest products, climate regulation through carbon fixation, crop and wild plant pollination by native insects, and recreational, esthetic or religious values. In some regions, the prospect of a warming climate portends a change for the positive: it will allow the production of new crops including cereals or wines of high market value, increased production of some forest species or more enjoyable weather for tourism. However, such positive changes and associated opportunities are not the rule: abrupt changes in ecosystem services associated with climate change are already being observed, and many more are expected (Mooney et al. 2009).

The destruction of entire ecosystems is the most extreme manifestation of the effect of a changing climate. Consider the case of coral reefs, which serve as nurseries for many fish species. As water temperatures rise, bleaching of reefs deprives local populations of important resources from fishing (Hoegh-Guldberg et al. 2007). Coral reef loss also exposes local populations to increased risks from storm damage. Furthermore, income from tourism is lost and thereby an important incentive for sustainable coastal management. Finally, we lose an irreplaceable cultural asset at a global level.

Another example comes from the southwestern United States. A regional-scale tree die-off in semiarid woodlands following the drought in the year 2000 has been referred to as an ecosystem crash (Breshears et al. 2011). The death of trees cascaded to widespread mortality of other species, from pinyon to juniper woodlands. This abrupt event likely altered most ecosystem services fundamentally, with both positive and negative effects. There were short-term effects on grass availability for ranchers (positive), culturally important products such as pinyon nuts (negative) and overall cultural landscape value (negative). Longer-term effects concerned soil erosion and regional climate through changed albedo.

At the planetary scale, although model projections remain conflicting, the shrinking of the Amazon rainforest due to climate change and ensuing land-atmosphere feedbacks has been shown to have potential dramatic consequences for global climate (Mahli et al. 2009). Seemingly less striking changes can entail equally dramatic consequences. Because biotas are the providers of ecosystem services, shifts in the distribution of functionally important species have the potential to disrupt ecosystem services. The distributions of plants and their pollinators can be modified independently from each other, either because of different response speeds or because they are driven by different climatic variables.

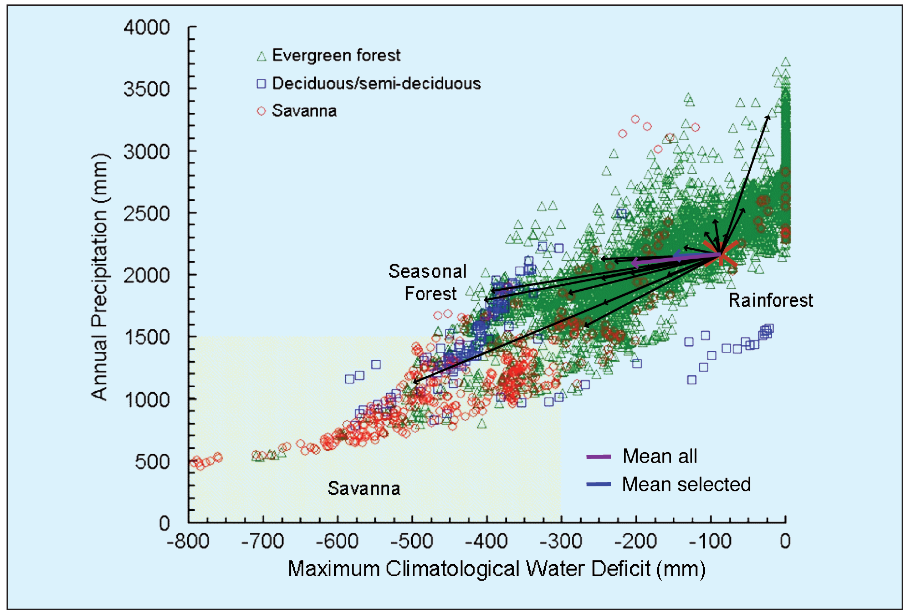

Figure 1: Type of vegetation in relation to rainfall in the Amazon region. The overlaid arrows show the trajectories of change as simulated by the 19 general circulation models used in the IPCC AR4 forced to start from the averaged observed climate over the period 1970-1999 AD (red star). The tips of the arrows represent the simulated late 21st-century (2070-2099 AD) rainfall regime. The purple arrow shows the mean of all model trajectories and the blue arrow the mean of all models that simulate the late 20th century adequately. Figure modified from Mahli et al. (2009).

Even before the changes in distributions, the subtle matching in phenologies between plants and pollinators is lost and so is the service of pollination, with costly consequences for food production and for culturally important rare species. Conversely, climate change is a golden opportunity for some pest species when their phenology or their distribution synchronizes with those of host plants. Several such cases have already been observed in forest species, such as the altitudinal expansion of the common mistletoe and of the pine processionary moth in the European Alps.

A spectacular case is that of the mountain pine beetle in North America (Kurz et al. 2008). With warming climate this species has been expanding northwards, affecting millions of hectares of coniferous forest. Compounded with increasing fire risk during warmer and drier summers, highly flammable beetle damaged forests have contributed to dramatic increase in burned areas, with considerable effects on regional carbon budgets (expected average emissions for western Canada: 36 g C m^{-2} yr^{-1}) and potential positive climate feedbacks. The same type of dynamics applies to invasive species, when the climate-driven expansion of exotics such as C_4 grasses into shrubby ecosystems (Australia, Cape Region of South Africa) profoundly modifies long-term fire regimes.

Such abrupt changes in ecosystem services are serious challenges to adaptive capacity. Learning from past events, detecting early warning signals and fostering resilience of socio-ecosystems will be essential.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Breshears DD, Lopez-Hoffman L and Graumlich LJ (2011) *Ambio* 40: 256-263
Hoegh-Guldberg O et al. (2007) *Science* 318(5857): 1737-1742
Kurz WA et al. (2008) *Nature* 452: 987-990
Mahli Y et al. (2009) *PNAS* 106(49): 20610-20615
Mooney H et al. (2009) *Current Opinion in Environmental Sustainability* 1: 46-54

Although "ecosystem services" is a relatively new term, the concept has a long history. For example, the 1895 New York State Constitution designated the Adirondack Forest Preserve to be "forever wild" in order to maintain water quality and supply in the Hudson River watershed. Ancient societies utilized such ecological goods as fuels, fibers, and foods deriving from natural or lightly managed ecosystems, and many came to recognize the ecological services provided by vegetated watersheds and floodplains. Such recognition often came the hard way, just as it does for modern societies.

Studies of the past play important roles in assessing risks and vulnerabilities for ecosystem services in two ways: by providing records of interactions among environmental change, ecosystem services, and societal activities, and by showing how ecosystem properties that underlie ecosystem services have been affected by climatic changes. Because human activities have affected ecosystems for centuries to millennia, it is particularly important to establish baselines for ecosystem properties and services, and to determine how those baselines have already been altered by humans. Teams of marine biologists and paleobiologists have documented history of human impacts on North American fisheries (Jackson et al. 2001; Jackson 2001). Although Native Americans harvested fish and shellfish, often intensively, estuarine ecosystems were little affected. However, introduction of European technologies led to rapid size decline of fish at the top of the food chain, and intensive oyster harvesting resulted in estuarine eutrophication. Both trends accelerated with industrial fishing of the 20th century, with multiple consequences for ecosystem goods and services.

In another example, alpine lake sediments in the western United States record a five-fold increase in dust deposition concurrent with intensive cattle and sheep grazing in the 19th century (Neff et al. 2008). Modeling studies reveal that the dust emissions, caused by breakup of soil crust and reduction of vegetation cover at low elevations, were sufficient to reduce snow albedo, shortening high-elevation snow-cover by several weeks and altering seasonal and total stream discharge (Painter et al. 2010). The sediment studies also show that federal grazing regulations introduced in the 1930s had mitigating effects on dust deposition (Neff et al. 2008).

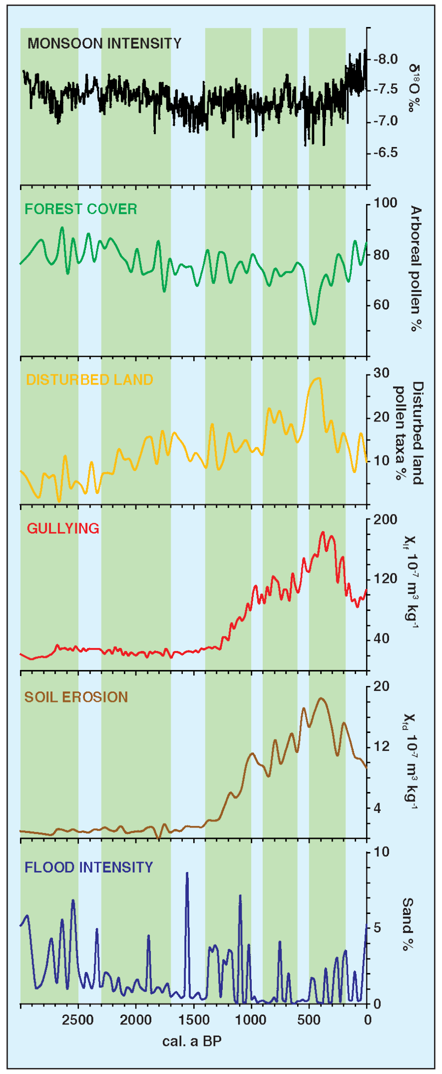

Figure 1: Geohistorical records of temporal changes in ecosystem properties and services. This 3000-year composite record of regional ecosystem attributes (land cover, erosion, flood intensity) inferred from sediments of Lake Erhai and monsoon intensity inferred from a speleothem shows ecosystem responses to changes in human population, cultural practices, and climate. The five green bands show primary periods of human effects on the regional environment (left to right): Bronze-Age culture, Han irrigated period, Nanzhao Kingdom, Dali Kingdom, and late Ming/early Qing environmental crisis. (From Dearing 2008).

These studies focus on impacts during the historical period, but ancient societies also provide object lessons on interactions among cultural practices, climate change, and ecosystem services (Costanza et al. 2007; Büntgen et al. 2011). Sediments from Lake Erhai in southwestern China show vividly how a succession of late Holocene cultures influenced land-cover, soil erosion, and flooding (Fig. 1), culminating in a peak of land clearance and soil erosion in the 17th and 18th centuries (Dearing 2008; Dearing et al. 2008). Consequences of land-use practices may have interacted with increasing monsoon intensity, leading to a well-documented environmental crisis that began to abate only in the 20th century.

Studies of environmental and ecological changes, even without direct links to cultural practices or consequences, play important roles in assessing ecosystem services. Ecosystem services ultimately derive from structural, functional, and compositional properties of ecosystems, and understanding how those properties have responded to past climate changes can provide insight into vulnerability of ecosystem services to ongoing and future climate change (Williams et al. 2004; Jackson 2006; Jackson et al. 2009). North American mid-continental droughts in the Holocene provide a series of case studies. Most recently, multidecadal droughts associated with the Medieval Climate Anomaly led to widespread changes in fire regime and vegetation composition in the central and western Great Lakes region (Shuman et al. 2009; Booth et al. 2012). In the mid-Holocene, a severe and persistent drought (ca. 4200-4000 a BP) resulted in forest disturbance and compositional change in the western Great Lakes as well as dune mobilization in the Upper Mississippi Valley (Booth et al. 2005). In the early Holocene, the mid-continent experienced a gradual, time-transgressive drying, punctuated by a rapid, region-wide drying associated with final collapse of the Laurentide ice sheet. Ecosystem responses show both gradual and time-transgressive trends and a step-change associated with the rapid event (Williams et al. 2009, 2010). Timing varied widely among individual sites, suggesting different thresholds and sensitivities of local systems. All these case studies indicate that ecosystem properties, and ultimately ecosystem services, are vulnerable to climatic change, whether transient or persistent, and that sensitivity varies substantially among ecosystems and regions.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

Costanza R, Graumlich LJ and Steffen W (2007) *Sustainability or Collapse? An Integrated History and Future of People on Earth*, MIT, 520 pp
Dearing JA (2008) *The Holocene* 18: 117-127
Jackson JBC et al. (2001) *Science* 293: 629-638
Neff JC et al. (2008) *Nature Geoscience* 1: 189-195
Williams JW et al. (2010) *Geology* 38: 135-138