SCIENCE POLICY

Navigating transformation of biodiversity and climate

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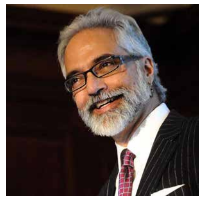

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> *"Biology must become central to climate change science and policy formulation. The planet does not work just as a physical system; that reality needs to become fundamental to the way we pursue the science and derive policy recommendations."*
>
> —Thomas E. Lovejoy (*1*)

This planet is the home of life, born into existence and transformed over 3.8 billion years into a continuous tapestry, covering all possible places from the deep ocean floors to mountain summits. Ours is a bioclimatic world in which every organism, from bacterium to blue whale, inseparably contributes to the climate and surface conditions of Earth. This tapestry, of which we are a part, is unraveling, with its delicate patterns and motifs denigrated to near invisibility, disappearing at a rate and magnitude that rivals that of the great mass extinction events of the past (*2*, *3*). This fading to nonexistence is making us unfortunate witnesses to the accumulated consequences of human actions over the past 10,000 years. Happily, though, we are now increasingly empowered by science and can act to abate ongoing trends and protect planetary resources before the essential threads of life's coherence become completely eroded.

Each year since 1995, participants in the United Nations Framework Convention on Climate Change (UNFCCC) meet as a Conference of the Parties (COP) to determine how best to address the increasingly harmful changes now taking place. This Special Collection of articles has been timed to coincide with the COP25 meeting scheduled to be held in Spain this year. The Collection provides comprehensive review articles and original research by leading authorities on recent advances in the study of interactions between biodiversity and climate that deepen our understanding of bioclimatic changes and can provide guidance on how best to navigate through the rapid alterations we are seeing today. Evidence here suggests that the negative impacts of climate change can be kept under control if we collectively act and, critically, use biodiversity as part of the solutions we invent. This overview provides a brief summary of the main topics addressed in the collection, each of which demonstrates how linking the management of biodiversity and climate might enable us to keep ongoing transformations in climate and biodiversity within safe operating boundaries.

EMBRACING COMPLEXITY: THE INTERTWININGS OF BIODIVERSITY AND CLIMATE

The history of the biosphere is one of coevolution between organisms and their environments with consequences at different scales of time, space, and organization. A classic example of this global reciprocity was the evolution of oxygenic photosynthesis, which put into motion a planetary level transformation known as the Great Oxidation Event (GOE). The GOE amplified concentrations of oxygen in our atmosphere and oceans, generated the planetary ozone layer, and laid the groundwork for the evolution of multicellular organisms (*4*, *5*). Additional links between large-scale changes in the Earth System and biodiversity range from glaciations to changes in the temperature of oceans, soils, and atmosphere (including the sequestration of CO_2 in plant biomass and soils) and the regulation of climate and CO_2 concentrations through the biological pump of the oceans. Although researchers and policymakers have long known that the chemical composition of our atmosphere and oceans is strongly affected by living matter (*6*, *7*), today application of this knowledge is changing as data reveal that these relationships are mediated by a plethora of deeply complex processes that, when perturbed, will morph in ways that are exceedingly difficult to predict.

Recognizing that transformations in climate and biodiversity are fundamentally unpredictable requires that conversations about planetary climate management shift to bring biodiversity into focus as a primary topic of discussion. An abundance of recent evidence now shows that even small, incremental, and/or sudden changes in climate can result in extreme events with large consequences that can, in turn, reduce the overall health of species. Declining species health can have powerful and negative consequences on populations, communities, and key ecosystems processes, which again in turn can increase the probability of additional cycles of unprecedented extreme events. Diffenbaugh and his colleagues (*8*) convincingly argue that effectively managing our climate will also require the incorporation of the high probability of unprecedented extreme climatic events as projected under cumulative emissions identified in the current National Determined Commitments (NDCs) (*9*).

In tandem with acknowledging that climate fluctuations are unpredictable in their timing, speed, and range, researchers are also coming to appreciate the foundational role of feedback mechanisms between the biosphere and the atmosphere, particularly those involving soils and plants. Two papers in this collection address the complexity of feedback processes. Quan *et al.* (*10*) provides experimental evidence and meta-analyses on ecosystem carbon fluxes and their feedback to warming, whereas Pugnaire *et al.* (*11*) review the evidence regarding plant-soil feedback (PSF) under pressures of climate, providing critical insights into the significant role of microbes within the plant-soil food web and how these interactions are reflected in the carbon cycle with measurable consequences for both climate and biodiversity.

Additional topics of interest in understanding the interlacing patterns of biodiversity and climate have focused on unknown roles of complex life cycles in species abundance under the influence of climate-induced change. Panetta *et al.* (*12*) explore this important area in a 25-year-long warming experiment that, combined with experimental manipulation of seed banks and historical plant surveys, allowed researchers to identify the mechanisms underlying the local extinction of a mountain plant. Enquist *et al.* (*13*) also address the issue of abundance documenting that the great majority of plant species on Earth are rare and tend to cluster in a small number of hotspots in areas that have been characterized by greater climate stability, which puts them at great risk from climate transformation. However, although our understanding of how species respond to climate transformations and humans impacts is impressive, we are just beginning to understand how these changes can propagate through ecosystems with broader ecological and evolutionary consequences (*3*, *14*, *15*). Bascompte *et al. (16)* further this understanding by chronicling how climate induced species loss reverberates through ecological networks, leading to further species changes, losses, and rearrangements.

The continuous rearrangement of ecological networks highlights the need for developing dynamic network models to more accurately assess climate and biodiversity transformations (*17*) especially in marine ecosystems currently subjected to many stresses. Convey and Peck's (*18*) review of changes in Antarctica and surrounding ocean ranges, for example, documents acidifying ocean waters, reduced oxygen in coastal and fjord ecosystems, and shifts in important land and water species. These changes in Antarctic ecosystems will affect global climate (*19*) and support the need for increasing close monitoring of this important marine ecosystem. The necessity of increasing efforts to monitor our changing climate is further underscored by Sumaila *et al.* (*20*), who argue that failure to enforce the Paris Agreement will result in climate transformations that have the potential to undermine essential food and economic resources.

BIODIVERSITY-BASED SOLUTIONS TO CLIMATE TRANSFORMATIONS

Despite the plethora of questions remaining about the functioning and complexities of biodiversity and climate networks, many agree that climate change can be mitigated by some clear and powerful actions. For example, there is robust consensus among researchers and policy makers that forcefully mitigating emissions from fossil fuel consumption across many sectors is among the most important actions that should be taken. But, in addition to abating emissions, several other new alternatives are gaining attention and traction, in part, because they are more crosscutting and generate multiple co-benefits for biodiversity—including humans—and ecosystem services. These "biodiversity-based" solutions (*21*, *22*) emphasize an ecosystem approach that is anchored in the carbon cycle and serves as the bedrock for the mitigation options underscored by both the Convention on Biological Diversity (CBD) and IPCC Working Group III (WGIII) (*23*, *24*). Fargione *et al.* (*25*) quantify the maximum potential of 21 such biodiversity solutions to increase carbon capture and storage and reduce greenhouse gas emission from ecosystems in the United States. Examples of these measures are the restoration of croplands to grasslands, forests, and wetlands, decreases in timber production, and reforestation in urban and degraded native forest areas, among others. These measures can provide up to 21% abatement of the U.S. emissions (using 2016 as baseline) and could provide important co-benefits such as water provision, erosion control, avoidance of toxic algal blooms, and hypoxic or "dead zone" events in coastal areas, among others.

Another complementary solution is "The Global Deal for Nature" (GDN) outlined by Dinerstein *et al.* (*26*) that aims to avoid catastrophic climate change, conserve species, and secure essential ecosystem services by emphasizing protection of natural ecosystems. Similarly, Tittensor *et al.* (*27*) emphasize the potential of protected areas in conserving biodiversity if climate is considered in their design and management and underscores the importance of this sort of strategy for marine protected areas (MPAs). Cámara-Leret *et al.* (*28*) describe the crosscutting nature of biodiversity solutions by showing that, in addition to increasing adaptation and helping mitigate transformation, protected areas also have important co-benefits by securing species that are important to our biocultural diversity and heritage.

The current climate crisis (*29*) is transforming our Earth and its systems and requires similar transformative responses on our part. Ongoing alterations will unveil new and unfamiliar terrain and, although we do not yet have clear assessments of or controls of the path ahead for the planet, we do know that we can and must use biodiversity as a central tool to navigate our biosphere safely through change. Researchers and policy makers must work together to bring the best scientific evidence to bear on global decisions needed to protect the planet. We need to rethink some of the basic tenants upon which global human civilization has grown including the notion of property rights and ownership on land and in oceans and of biodiversity and its services.

Science supports a view of Earth as a complex network of inextricably intertwined interactions of climate and biodiversity; as stewards of Earth, we must begin to function as a coherent civilization to enact, share, and teach values that reconnect us, as critical threads in the tapestry of the biosphere and, in so doing, with ourselves. As the Chilean Nobel laureate poet Gabriela Mistral once wrote "Humanity is still yet to be humanized."

–Pablo A. Marquet, Shahid Naeem, Jeremy B. C. Jackson, Kip Hodges

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