



# Interactions between changing climate and biodiversity: Shaping humanity's future

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Scientists have known for more than a century about potential human impacts on climate (1). In the last 30 y, estimates of these impacts have been confirmed and refined through increasingly precise climate assessments (2). Other global-scale human impacts, including land use change, overharvesting, air and water pollution, and increased disease risk from antibiotic resistance, have risen to critical levels, seriously jeopardizing the prospects that future generations can thrive (3–5). Earth has entered a stage characterized by human domination of critical Earth system processes (6–8). Although the basic trajectories of these changes are well known, many of the likely consequences are shrouded in uncertainty because of poorly understood interactions among these drivers of change and therefore their effects on ecosystems and societies.

## Drought Impacts on Diversity

Harrison et al. (9) provide a window into one important set of these interactions through their analysis of the relationship between drought and plant diversity and their temporal trends in California. This study confirms the well-recognized pattern that regions that are warm and wet support more species than those that are cold or arid (10–11). They also show that this same pattern consistently emerges at local scales and even among plots within a single site, suggesting a causal relationship. More importantly, these same patterns are mirrored in diversity loss over time during California's recent drying trend (9).

Global climate is now warming rapidly, and nearly half of the terrestrial surface is expected to experience less water availability during the growing season (12). Extrapolation of these trends, supported by the temporal analyses of Harrison et al. (9), leads to the prediction that plant diversity will decline in much of the world, especially where water is already strongly limiting. On average, terrestrial ecological communities are estimated to have lost more than 20% of their original biodiversity (13), with past and projected biodiversity loss in arid ecosystems likely to be even greater (9).

Harrison et al. (9) note that the climate–diversity relationship they document is consistent with a climatic tolerance model in which the least drought-tolerant species are the first to be lost as climate dries. According to this model, drought acts as a filter that removes more-mesic-adapted species. Since the end of the Eocene, about 37 million years ago, California's ancient warm-temperate lineages, such as redwoods, have retreated into more-mesic habitats, as more-drought-adapted lineages like oaks and madrone spread through California. Perhaps this history of declining mesic lineages will repeat itself, if California's climate continues to dry over the long term.

The Harrison study (9) documents several dimensions of diversity that decline with drought. The decline in taxonomic diversity (expressed as species richness) is not random but is paralleled by declines in phylogenetic diversity (measured as the mean branch length separating pairs of coexisting species) and functional diversity (measured as functional dispersion, an indicator of the range in functional trait values). Plant height and, less consistently, foliar nutrient concentrations and specific leaf area (leaf area per unit mass) show greater diversity in benign climates, and multivariate functional diversity declined over time with drought-induced species loss. In general, the species most likely to persist were those that are drought tolerant. Species from stressful environments (those that are dry, nutrient impoverished, or cold) tend to have traits that support lower productivity (14). The decline in multivariate functional diversity is important because, even if drying trends ceased, the increasingly drought-adapted flora would likely have a lower productive capacity than the species that were initially present. Documentation of this shift in functional traits is pragmatically important to incorporate into global models to improve their capacity to project long-term changes in productivity and stress tolerance as vegetation changes in response to climatic change.

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Author contributions: F.S.C. and S.D. wrote the paper.

The authors declare no competing interest.

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See companion article, "Climate and plant community diversity in space and time," [10.1073/pnas.1921724117](https://doi.org/10.1073/pnas.1921724117).

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First published March 9, 2020.

## Warming Impacts on Diversity

Changes in plant diversity as tundra warms are more equivocal than the consistent decline in plant diversity in drying landscapes observed by Harrison et al. (9). Analogous to dry landscapes, arctic and alpine ecosystems have lower diversity than ecosystems in more-mesic environments (15–16), suggesting that they might gain diversity as climate warms. Consistent with this expectation, mountain peaks have increased in plant diversity, as subalpine species, especially species that are larger in size and have greater specific leaf area, move upslope (17). In arctic tundra, plant height also increases in parallel with recent climate warming (18). However, overall plant diversity and other plant traits associated with warmer, more productive ecosystems have shown no consistent change, because of both data limitations and, perhaps, the counteracting effects of dryness as tundra warms.

## Consequences of Diversity Changes

Until recently, most global biodiversity loss reflected the conversion of natural ecosystems such as tropical forests and wetlands to human-dominated landscapes. This suggested that conservation efforts to protect critical natural ecosystems would be the most effective strategy to stem these declines. The increasing

importance of climate change as an additional contributor to nature's decline (19–20) suggests that a much more fundamental change in societal patterns of resource consumption and energy use is required if current trends in biodiversity loss are to be curtailed (5).

Arid regions support some of the world's poorest people. These people generally lack the power and financial resources to supplement, with mainstream technology, the water that is gradually being lost through heat-driven increases in evaporation. However, cultural traditions developed in arid regions often convey knowledge and practices that enabled people to cope with drought over centuries (21). If current trends of increasing aridity continue in dry parts of the world, local people must be empowered to tap both technology and their cultural traditions as they seek to cope with increasing drought. These people may have important lessons to teach others living in more-mesic regions where drought adaptation is less culturally embedded. More importantly, emerging consequences of climate change increase the urgency for higher-income regions of the world to reduce rates of energy use and resource consumption that ultimately contribute to the currently observed trends toward drought and biodiversity loss.

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