PNAS OPINION

Human responses to climate change will likely determine the fate of biodiversity

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Although not directly attributable to climate change, the plight of Rohingya refugees, seen here building makeshift shelters in Bangladesh in 2017, illustrates how climate-induced human population displacements could affect biodiversity. When local residents won't accept influxes of "foreigners" into their communities, any remaining natural areas in the vicinity could be targeted for land conversion and development to support these displaced persons. Image credit: Shutterstock/Sk Hasan Ali.

Climate change is an existential threat to humans and global biodiversity, as was reinforced in the sixth assessment report (1) of the Intergovernmental Panel on Climate Change (IPCC), as well as Conferences of the Parties of the IPCC (Glasgow, UK; November 2021) and the UN Convention on Biological Diversity (Montreal, Canada; December 2022). But these gatherings also implicitly highlight severe shortcomings in how conservation scientists and policymakers are addressing the climate change threat.

Research in climate change ecology and conservation is still dominated by attempts to understand how species are vulnerable to the altered abiotic conditions driven by climate change alone (e.g., rising temperature) (2). This threat is undoubtedly important. But we argue that other facets of climate disruption could have vastly greater impacts—in particular, the ways in which climate-altered human societies, demographics, and economies interact with natural ecosystems and species. Unfortunately, these human dimensions of climate change ecology have received scant attention. Broad-scale assessment of the scale of biodiversity responses to climate change (3) are therefore underestimating the problem—potentially on a massive scale—when only incorporating direct, abiotic impacts.

Climate change is often considered to be one of the threats facing biodiversity, distinct from other threats and not considered—at least currently—to have as strong an impact as habitat loss and overexploitation (4, 5). But rather than being a separate factor, climate change magnifies these other threats and is now exacerbating all of the pathways by which humans directly cause species endangerment (Fig. 1). Policymakers and planners still do not recognize this combined impact

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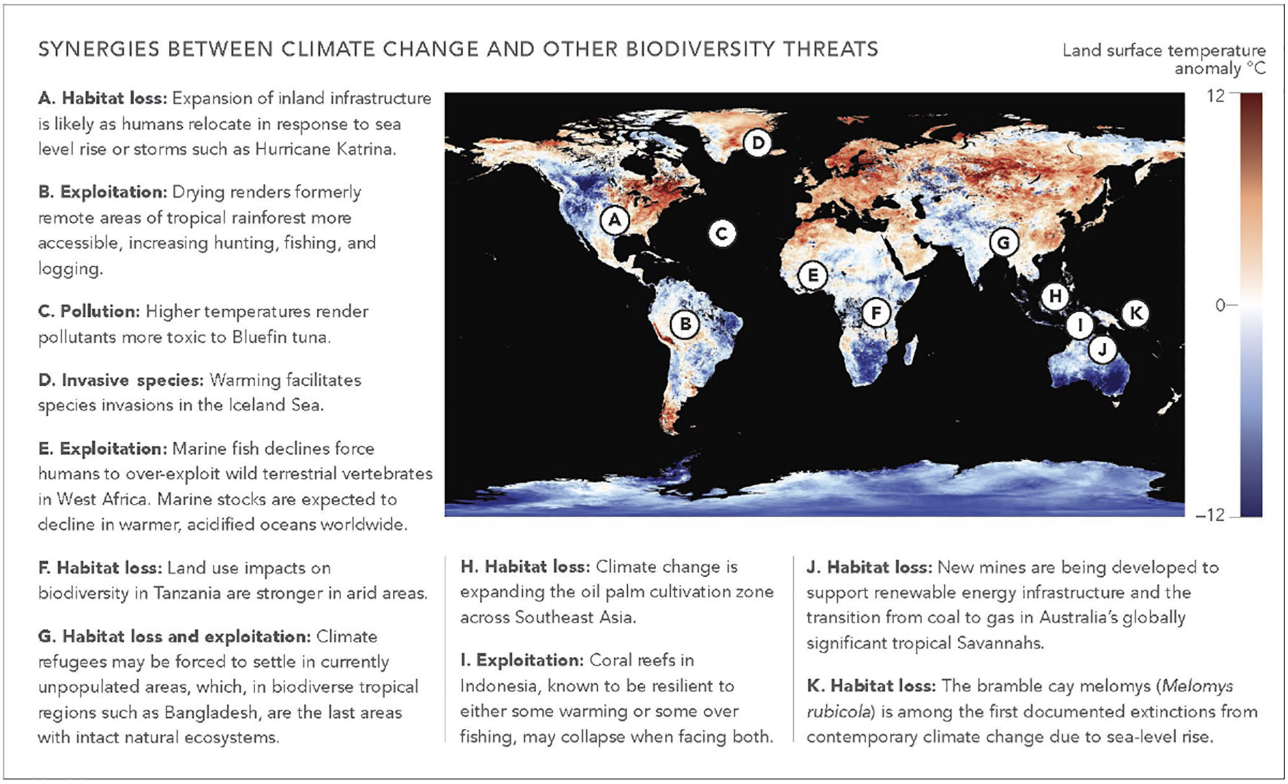

Fig. 1. The widespread ramifications of climate change are already having complex knock-on effects on biodiversity. Image credit: Map from NASA Earth Observations team based on data provided by the Land Processes Distributed Active Archive Center and the MODIS Land Science Team. Adapted from by Lucy Reading-Ikkanda (artist).

when considering how to abate climate disruption and biodiversity loss. Indeed, it is these synergies, along with the pace of change, that make the current extinction crisis unique in Earth's history. Although global climate change of about 6 °C caused Earth's biggest mass extinction event to date (at the end of the Permian), this phenomenon likely occurred an order of magnitude more slowly than what we are inducing today—and in a world without significant habitat loss, degradation, and other biodiversity threats from the actions of a single species.

Appreciating the Complexity

Although conservation efforts have been key to slowing recent losses of biodiversity, scientists and decision makers need to stop viewing climate change as just another separate threat to Earth's biosphere. Climate change magnifies the intensity of the other drivers of biodiversity decline, such as habitat loss, overexploitation, and invasive species. Regional drying is making formerly remote areas of tropical rainforests accessible, thereby increasing hunting, fishing, and logging pressure (6). Warming can expand the cultivation zone of cold-intolerant crops upwards in elevation, threatening montane areas with deforestation and land conversion (7). Climate-facilitated expansion of oil palm (*Elaeis guineensis*) cultivation in Southeast Asia, for example, would threaten native species in these hyperdiverse systems much more than either habitat loss or climate change alone (7). Rising ocean temperatures can increase the spread of invasive species (8) and make environmental pollutants more toxic (9) (Fig. 1). Evidence increasingly shows that the destruction of coral reefs is particularly acute when warming waters act in combination with other stressors; plastic pollution, overfishing, and crown-of-thorns starfish (*Acanthaster planci*) outbreaks all interact synergistically with rising ocean temperatures to inhibit coral fertilization and larval recruitment (10). Loss of coral reefs can then cascade to harm at least two of the other highly diverse (and economically important) marine ecosystems, mangroves and seagrasses, through altered pH buffering, sediment capture, and abundance of shared animal species (11).

In turn, non-climatic biodiversity threats can intensify climate change impacts. Nutrient loading and turbidity from agricultural runoff and logging-induced erosion render corals more susceptible to mortality in the face of warmer temperatures and more-frequent storms (10). Fear of introducing potentially invasive species is slowing or preventing the widespread adoption of assisted colonization as a strategy to ameliorate climate change impacts (12); the bramble cay melomys (*Melomys rubicola*) is among the first documented extinctions from contemporary climate change—a loss that was preventable. Although ecologists have done a thorough job of addressing the direct impacts of changing abiotic conditions on organisms (e.g., 3), synergies between climate and other anthropogenic impacts have received much less attention.

Millions of people are already being displaced because of climate change, movements that will likely become the largest human migrations in history (13). How nations deal with the influx and outflow of climate refugees will affect every aspect of society, including biodiversity conservation. Forests and wildlife in the global biodiversity hotspot of South Asia, for example, are undoubtedly affected by rising temperatures and altered precipitation. And yet, over the next 30 years, they may be much more strongly affected by tens of millions of people dispersing throughout the region after rising seas inundate much of Bangladesh. The recent floods in Pakistan further showcase the devastation of climate change-induced extreme weather events, with crops, villages, and even cities almost entirely destroyed, leaving hundreds of thousands of people destitute. How the country rebuilds its agriculture and population centers will have a massive impact on its biodiversity.

The ongoing situation in the Kutupalong and Nayapara Refugee Camps is an early warning of how such processes could play out over much of the world. The camps support nearly a million Rohingya refugees fleeing persecution in neighboring Myanmar. In densely populated Bangladesh, rather than trying to house the people in already-developed areas such as cities or crop lands, the government has donated forested area to the refugee camps, including degazetting 2,500 ha of the Teknaf Wildlife Sanctuary (14). The urgent need for living space, building materials, and firewood has, unsurprisingly, led to rapid deforestation, with the surrounding forest cover halved over just two years (14). This habitat destruction and disturbance have greatly increased human–elephant (*Elephas maximus*) conflicts (15). Overhunting in the remaining forests has caused the local extirpation of wild pigs (*Sus scrofa*), Indian rock pythons (*Python molurus*), Bengal monitor lizards (*Varanus bengalensis*), and other species (14). Although not directly attributable to climate change, the Rohingya refugee crisis serves as an important example of how ongoing and future climate-induced human population displacements could affect biodiversity. In many parts of the world, residents will be unwilling to accept huge influxes of "foreigners" into their communities. Any remaining natural areas in the vicinity are likely to be targeted for land conversion and development to support displaced persons. Governance and funding at national and international scales are woefully inadequate to mitigate the looming humanitarian and biodiversity crises wrought by major displacement of climate change refugees (16).

Climate change is also reducing—often devastatingly—agricultural output and fresh water availability in many areas, which stresses societies and increases warfare (17). The onset of the civil war in Syria, for example, was at least partially caused by a major drought (18). In Somalia, a drying climate has helped fuel intranational warfare and refugee movements, which in turn have exacerbated deforestation (19). Although understudied, the impacts of more frequent wars on biodiversity could be considerable. Wars destroy habitat and increase wildlife poaching, leading, for example, to the extirpation of the African elephant (*Loxodonta* spp.) from half a dozen countries (20). Warfare displaces people, bankrupts national economies, and dissolves the financial and political capital to conserve biodiversity.

In many regions, climate change will destabilize food security and access to natural resources. Where humans turn for new resources will profoundly affect ecosystems and species. Globally, humans capture more than 80 million tons of marine fish per year (21). How will we replace this protein as commercial stocks decline in warmed and acidified oceans (2)? Increasing livestock production to compensate would dramatically increase habitat loss and methane emissions. And turning from fish to wild meat would rapidly deplete stocks of almost any terrestrial vertebrate. Warming temperatures could reduce cereal crop yields in many regions (22), leading to further expansion of agriculture, the single biggest driver of habitat loss.

In some areas, even "green energy" solutions, meant to slow the pace of climate change, are likely to have substantial biodiversity impacts. The growing renewable energy sector is driving the expansion of mines around the world, and much of the increased mineral extraction is occurring in areas set aside for biodiversity conservation. Of the area affected by mining globally, 16% is in Remaining Wilderness, 8% in Protected Areas, and 7% in Key Biodiversity Areas (23). Likewise, "clean" energy infrastructure, such as wind and solar power, require large land allotments outside of inhabited and agricultural areas, so as to not negatively impact other societal needs. In other words, renewable energy expansion will often occur in natural areas, as demonstrated with newly planned wind farms in Queensland, Australia (24).

Taking Action

Understanding and addressing the synergies that we outline here will be extremely complex. There are huge numbers of scenarios for how climate change could affect warfare, refugee movements, agricultural output, resource extraction, and other factors, all with large uncertainties and potential interactions with other processes both known and currently unknown. This complexity makes it extremely difficult to predict, with any degree of certainty, the multifarious impacts of climate change on biodiversity. Indeed, such difficulties could partly explain why climate ecology research has hitherto focused so heavily on the comparatively simple task of assessing species' direct vulnerability to abiotic changes.

But these difficulties should not deter us from trying. Collaborations with human demographers, natural resource economists, and futurists will be critical, along with the recognition that the problems we face are highly interlinked. Successfully dealing with the impacts of climate change on biodiversity will mean working with human communities to reduce their vulnerability to climate disruption, particularly for the poorest and most vulnerable groups who have immediate adaptation needs (25). Emerging ecosystem service approaches to climate adaptation use elements of nature to buffer human communities against the adverse impacts of climate change (e.g., ecosystem-based adaptation). But for these to generate positive biodiversity outcomes, they must be focused on dual benefits for nature and human communities.

We need systemic change in how biodiversity is viewed and accounted for, so as to mainstream fundamental alterations in industries, land use, and planning, to counterbalance negative impacts on species and the climate system. The timing of this change is critical in light of the recent negotiations around the Conference of the Parties to the Convention on Biological Diversity (CBD), the foundational intergovernmental agreement on species conservation that will set the international conservation agenda for the next several decades. Many of these parties—and the scientists who are providing guidance to them—recognize that time is running out for changing the current trajectory of global biodiversity. In the implementation phase of the CBD's post-2020 Strategic Plan for Biodiversity comes an important opportunity to set global standards and metrics for nations and industry. We need policies and strategic initiatives that address biodiversity in the context of the human responses to climate change that are taking place now. This can only happen with broad recognition from scientists and policy-makers of how biodiversity and conservation contribute to economies and society—in ways that, to date, have been vastly underestimated.

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