

## Spotlight

### Future climate and land use threaten terrestrial diversity

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**Climate and land use change are major threats to biodiversity. Hari *et al.* quantify their combined impacts on future terrestrial vertebrate diversity, revealing pronounced regional differences and potential mitigating or exacerbating effects under different scenarios, underscoring the need for transformative climate and land use actions to halt biodiversity loss.**

Climate and land use change are two major threats to biodiversity, with their impacts likely to accelerate in the coming decades [1–5]. Threats to biodiversity rarely act independently, but understanding their individual and combined effects remains a major challenge, hampered by modeling and data limitations [2,4]. The extent and type of vegetation cover significantly affect local climatic conditions, with the conversion of natural habitats to human-dominated land uses (such as agriculture and urban areas) leading to warmer and drier conditions. Climate change can affect habitat extent and quality via, for example, increased frequency of extreme droughts and fires, and can directly affect species and populations, for example, by prompting individuals to shift their distributions as areas become more or less climatically suitable [6]. In turn, land use can facilitate or hamper organisms' ability to disperse [6]. Given their ubiquitous impacts, understanding the joint effects of land use and climate change is a fundamental research area [2].

Hari *et al.* [7] show that global terrestrial vertebrate diversity is highly sensitive to the joint pressures of future climate and land use changes, revealing pronounced differences among regions, taxa, and two contrasting socioeconomic and climate futures, underscoring the potential for land-use-based mitigation given the increasing projected impacts of climate change [2,4]. The study reveals strong spatial variation in the projected changes in vertebrate diversity, with climate-driven declines in richness at low- and midlatitudes, and increases at higher latitudes, consistent with time series and range shift analyses [6,8]. Additionally accounting for future land use change leads to higher spatial variability and crucially reveals its moderating effect under a sustainability scenario. Overall, steeper declines are projected under the combined effects of stronger land use and climate changes. By 2080, both drivers will play comparable roles in the decline of vertebrate diversity across low- and midlatitudes. Sub-Saharan Africa emerged as a particular hotspot of risk, with pronounced declines driven by extensive agricultural expansion and deforestation under the worst scenario. Tropical regions are at higher risk of biodiversity loss, as they hold a disproportionate amount of global biodiversity while being subject to intense and interacting pressures [4,9]. Finally, stronger climate-driven losses were projected for mammals, while amphibians were particularly vulnerable to land use changes. Globally, 91–94% of land area was projected to experience gains or losses of species by either driver. Crucially, the study highlights how sustainable land use policies can act as a major lever for alleviating future biodiversity losses.

#### Quantifying the double threat from climate and land use change

Most previous studies projecting biodiversity change focus on climate or land use separately. Hari *et al.* [7] employed a two-step framework coupling climate-driven

species distribution models (SDMs) with habitat-based land use filtering for 13 903 species of amphibians, birds, and mammals, leveraging high-quality global datasets of climate and land use. First, they estimated each species' probability of occurrence under current and future climate projections at 0.5° resolution globally. Then, the climate SDM-based probability of occurrence for each species was weighted by the fraction of suitable land use categories in each grid cell—a key improvement, 'requiring' that both the future climatic conditions and the land use type are suitable for each species. These 'refined' probabilities of occurrence were then summed for each taxon to compare the number of species expected to occur in each grid cell between present-day (1995) and future (2050 or 2080) periods, under two different scenarios of change representing low- and high-emission contexts with different land use trajectories.

Several important limitations need to be considered. First, the analysis used only four coarse land cover classes (forested land, nonforested land, pasture, and cropland), strongly simplifying land use and habitat classifications and ignoring land use intensity, which directly impacts diversity [3]. Additionally, pooling primary and secondary forested land, and savannahs and wetlands, as well as not distinguishing plant species within land use categories, could lead to significant differences due to species habitat requirements and restoration and afforestation strategies [7,10]. Second, using a single integrated assessment model to generate the land use trajectories under a 'biodiversity-conscious' outlook, which assumes global forest cover increase, likely leads to optimistic outcomes. Scenario-based modeling is a powerful approach to assess the impact of alternative future socioeconomic development pathways on biodiversity, but projected changes vary among scenarios and modeling assumptions [2–5,11]. Indeed, the projected richness increase

at higher latitudes was sensitive to the underlying dispersal assumption, with fewer gains in higher latitudes and more losses in midlatitudes under a no-dispersal model. Third, narrow-range species were not included, while known limitations of SDMs include the assumption of niche conservatism and the disregard of biotic interactions. Additionally, extreme events are likely to compound the estimated effects of climate change, while 'no-analogue' climates (climatic combinations that do not exist today) remain an important blind spot in many projections, further complicating the spatial variability of risk. Fourth, relying on the probability of occurrence does not account for extinction debt, as species may remain present in a given region but with declining abundance, eventually becoming extirpated. Finally, changes in

richness may be decoupled from changes in species composition, which has emerged as a key signal of biodiversity change [8].

### Land use can mitigate or exacerbate the effects of climate change

Hari *et al.* [7] show how trajectories of land use change can modulate climate change impacts (Figure 1). Under a sustainability scenario, which assumes strong land use regulation, climate mitigation, and reduced tropical deforestation, land use acted as an alleviating factor, with diversity losses dampened and gains amplified in most regions. Conversely, it exacerbated losses beyond the effects of climate change alone under an inequality scenario with limited regulation and low mitigation, resulting in significant deforestation,

pasture expansion, and high inequality. This suggests that while climate mitigation via reducing emissions alone may be insufficient to halt biodiversity declines, adopting sustainable land use strategies can partially offset climate-driven losses.

Growing evidence that land use strongly dictates climatic resilience [2,4,11] aligns with the overarching need to implement transformative actions to address both the climate and biodiversity crises. For instance, the recently approved EU Nature Restoration Law, a major pillar of the EU Biodiversity Strategy, sets binding targets to restore degraded ecosystems, aiming to enhance biodiversity while increasing carbon storage and climate resilience. Nevertheless, trade-offs between strategies and the strong context-dependency of land use impacts among habitats and taxa remain key challenges for policy, with potential conflicts between mitigation, restoration, and conservation. For instance, land use policies designed for direct climate mitigation, such as planting bioenergy crops, can negatively impact vertebrate diversity [3,10], while outsourcing biodiversity footprints and environmental impacts from Global North to Global South countries risks blurring national targets with overarching biodiversity and climate mitigation aims. A critical remaining gap for future global biodiversity assessments is to quantify the potential interactive, rather than additive, effects of climate and land use change [12], whereby their combined impacts are more pronounced than if either driver occurred alone. Hari *et al.* [7] contribute valuable quantitative insights to guide research and policy to halt biodiversity loss, underscoring the dual need for integrated global climate and land use change scenarios and regionally tailored conservation and mitigation policies.

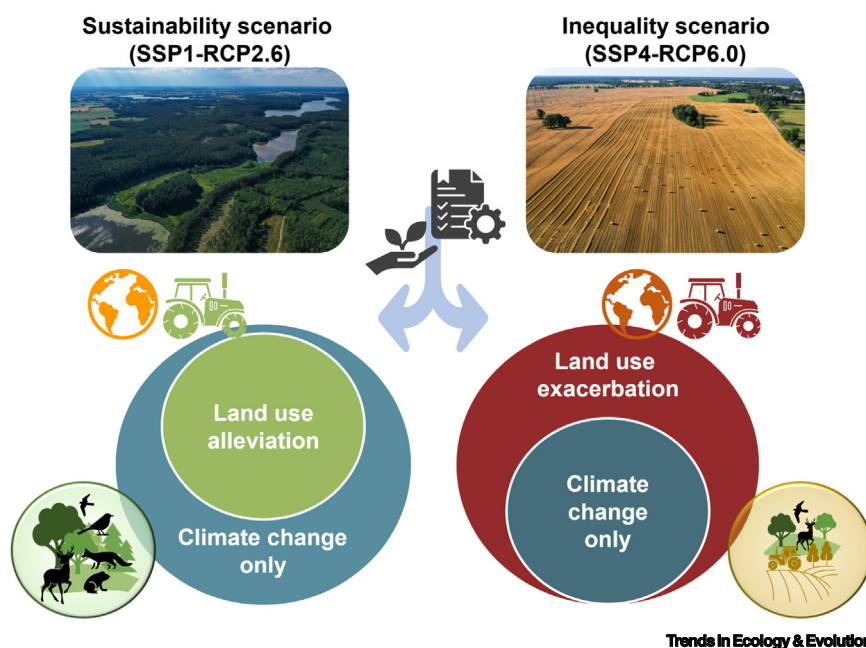


Figure 1. Effects of future climate and land use changes on terrestrial vertebrate diversity following two different socioeconomic and climate futures, illustrating how sustainable and mitigation policies can alleviate their impacts under a sustainability scenario compared with a worse inequality scenario, where impacts are exacerbated. Note this is a simplified summary, as Hari *et al.*'s findings reveal pronounced differences among regions and taxa. Icons were obtained from the Noun Project under CC BY 3.0: 'Bird' icons by Peter Chilton and Hea Poh Lin; 'Fox' by Andreas Reich; 'Deer' by naomi argi; 'Policy' by Tamrin; 'Globe' by Suryaman; 'Agriculture' and 'Tractor' icons by Ahmad Ishaq. Photos by Marcin Lewicki (lewickistudio) from Pixabay (<https://pixabay.com/photos/lake-nature-water-forest-mazury-8841339/>), <https://pixabay.com/photos/field-straw-agriculture-8885590/>).

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### Declaration of interests

The author declares no competing interests.

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