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For a Future Informed by Science at the Climate-Ecology Interface

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1 | Introduction

The Earth is facing climate and nature crises. In 2024, global mean temperatures surpassed 1.5°C above pre-industrial levels for the first time, and unprecedented extreme weather events—many attributable to climate change—were experienced around the world (World Meteorological Organization 2025). Concurrently, the IUCN Red List recognises 47,000 species threatened by extinction, of which climate change and extreme weather are known to be contributing to extinction risk for more than 7500 species (IUCN 2025).

Climate change is an increasingly important driver of declines in species and ecosystems (Isbell et al. 2023; Thierry et al. 2022). In turn, biodiversity loss fundamentally undermines crucial climate change resilience building and adaptation strategies (Seddon 2022). Climate-resilient development depends on healthy, functioning ecosystems, which in turn rely on intact species assemblages and resulting ecological processes (Isbell et al. 2023; Pecl et al. 2017).

The mechanisms tying climate and nature together are complex and diverse, but it is clear that the fates of both, and that of society, are inextricably linked. The Sixth Assessment Report of the IPCC's Working Group II was the first of its kind to recognise the interdependence of climate, ecosystems, biodiversity and society (IPCC 2022), and relevant to the aims of this special issue, situated the discussion of climate change risks and adaptation within the concurrently unfolding biodiversity crisis. Meaningfully and effectively understanding, predicting and preparing for the impacts of climate change is impossible without consideration of nature, and vice versa (Pettorelli et al. 2021). Addressing these joint crises therefore necessitates an interdisciplinary approach.

This special issue emerged from conversations started at the Climate Science for Ecological Forecasting Symposium, jointly organised by the British Ecological Society and the Royal Meteorological Society (Boult et al. 2022). The symposium highlighted the incredible potential for interdisciplinary collaboration to improve both ecological and climate prediction, and in turn, enable evidence-based decision-making to mitigate climate change and minimise biodiversity loss.

The papers published in this special issue demonstrate innovative approaches at the climate-ecology interface. Papers fall into three broad categories: (1) those predicting future climate change impacts on ecology, (2) those demonstrating the importance of ecosystems for climate change mitigation and adaptation and (3) those proposing methodological advances for the benefit of science and practice at the climate-ecology interface. Below, we use these categories to thematically structure our discussion of key aspects of the papers in this special issue. We hope that this joint special issue acts to cross-fertilise research agendas, encourage further interdisciplinary collaboration and highlight where more work is needed to inform policy, planning and practice.

2 | Climate Impacts on Ecology

The special issue comprises a series of papers anticipating the impacts of meteorological and climatic conditions on a range of ecological entities. Bourne et al. (2025) focus on untangling the relative roles of climate and land-use land-cover (LULC) change on riverine health as measured by macroinvertebrate species richness. Historically, statistical approaches have struggled to resolve the multiple, interacting and non-linear mechanisms underpinning riverine health and this has limited evidence-based management. Instead, Bourne and colleagues utilise a random forest model relating riverine health to LULC, water quality and hydraulic variables, recognising that machine learning approaches relax the need to define relationships between variables. They force this model forward under combined climate and LULC scenarios, and find that, while climate change has a seasonally varying impact on riverine health, suburbanisation clearly and consistently contributes to riverine degradation under all climate scenarios. Bourne et al. (2025) promote this as evidence to inform local level planning (i.e., urban densification rather than suburbanisation) for the benefit of riverine health.

Similarly, Cartwright et al. (2024) consider how climate change, and associated changes in ocean conditions, will likely affect the coral reefs of Western Australia. Near-coastal ecosystems, including coral reefs, are considered particularly vulnerable to climate change as many exist close to their thermal and turbidity tolerance limits. Based on long-term historical records of meteorology, ocean conditions and turbidity, Cartwright and colleagues develop a model to predict how combined future climate change, wave dynamics and sea level rise will impact coral reefs. They find that the coral reefs of Western Australia are likely to be exposed to increased sea surface temperatures (SSTs), sea level rise and, in some locations, higher turbidity, but that impacts on reefs will vary spatially. Cartwright and colleagues demonstrate that in some places, combined changes in SSTs, sea levels and turbidity will push corals beyond tolerance limits resulting in degradation and structural and compositional changes, whilst in others, changes from current conditions may have neutral or even positive effects on coral reefs, and should therefore be protected as future refugia.

Black et al. (2024) combine knowledge of climate dynamics with elephant physiology to predict the changing occurrence of elephant-relevant droughts—defined as two or more consecutive below-average rainy seasons—under future climate change. In alignment with previous studies, Black et al. (2024) find that East Africa is expected to become wetter under climate change while southern Africa is expected to dry. This culminates in a reduction in elephant-relevant drought in East Africa, but an increase in southern Africa where such events are currently extremely rare. The authors go on to evaluate the potential of seasonal rainfall forecasts for anticipating and preparing for elephant-relevant droughts—the use of seasonal meteorological forecasts being currently severely limited in conservation planning—but find there is insufficient skill in seasonal forecasts when predicting a second below-average rainy season. Black et al. (2024) conclude that even in regions with the greatest skill, only low cost, low regret actions may be triggered by current seasonal forecasts, but recommend that conservation practitioners look to the agricultural and humanitarian sectors for guidance on acting under uncertainty, that meteorologists seek to coproduce forecasts with conservation practitioners, and that further research on the drivers of prolonged drought in Africa is prioritised.

Smith et al. (2024) focus on shorter forecast horizons to predict wheat rust outbreaks in Nepal. Rust pathogens are a common problem for farmers in southern Asia. Their ability to disperse over long distances, driven by meteorological conditions, increases transmission risks across international boundaries and disrupts national control programmes, threatening livelihoods and food security. Effective control of rust pathogens depends on early warning systems (EWSs) enabling farmers to proactively apply fungicides. Existing EWSs rely on field surveillance by trained experts to identify emerging infections which are subsequently input into weather-driven dynamic models to predict dispersal, with advisory reports then issued to communicate risk. However, given the ability of rust pathogens to disperse over long distances, this EWS is only effective if surveillance takes place in a timely manner across a large region, which is costly and requires international coordination. Smith and colleagues exploit local media reports of rust outbreaks from neighbouring countries to act as a novel proxy for field surveillance data. They found that media reports in Pakistan and India recognised outbreaks up to 23 days before field surveillance identified the infection in Nepal. Using this approach retrospectively, Smith et al. (2024) were able to determine that meteorological conditions driving spore dispersal from India and Pakistan better explained Nepal's 2020 wheat rust outbreak than local transmission, and demonstrate how media reports can be leveraged and combined with meteorological forecasts to predict societally relevant impacts.

The final paper in this theme considers not the impact of climate change itself, but the contested role of certain climate change mitigation measures. The burning of forest biomass as an energy source is widely regarded as supportive of the move away from fossil fuels towards renewable energy. Indeed, in the European Union, bioenergy is currently the main source of renewable energy. However, Mackey et al. (2025) dispute the assumption that burning of forest biomass for energy is carbon neutral. The authors argue that research suggesting so relies on model assumptions that ignore known facts regarding emissions (emissions from burning of biomass are instant, but their net removal via regrowth is not), that models use inappropriate reference levels (emissions not fully reported), that scenarios are unrealistic (assuming biomass replaces fossil fuels) and that an important carbon pool is ignored (i.e., logging residues). Further, negative impacts on forest structure, composition and function, and consequences for biodiversity are well-documented (e.g., the depletion of soil organic matter, soil erosion and drying, reduction in saproxylic species, loss of habitat resources and reduced habitat connectivity). This reduces the resilience of forest ecosystems and the adaptive capacity of biodiversity, undermining key ecological processes, reducing biotic control of microclimates and increasing exposure to extreme weather. Mackey et al. (2025) conclude that the burning of forest biomass for energy therefore does not qualify as climate resilient development and instead undermines adaptive capacities and amplifies climate risk.

3 | Ecosystems for Climate Adaptation

The IPCC Sixth Assessment Report of WGII recognises extensive human dependence on ecosystems services in Africa, and highlights ecosystem-based adaptation as a cost-effective means to build climate resilience while providing social, economic and environmental benefits (Trisos et al. 2022). To that end, two papers included in this special issue highlight the need to protect ecosystems to ensure climate change adaptation potential is maintained, both with examples from Africa. Manyakaidze et al. (2025) document the reliance of smallholder farmers on the Nyororo wetlands in Zimbabwe as an adaptation strategy during drought. The authors adopt a mixed-methods approach combining qualitative information from household surveys, focal group discussions, and key informant interviews with quantitative remotely-sensed measures of wetland health. From their study, it is clear that the wetlands are an increasingly important source of resilience for smallholder farmers in the face of climate change, but that wetlands are receding, likely due to climate change and the increased reliance on wetlands for water, irrigation and livestock. Manyakaidze et al. (2025) recommend a number of resilience building strategies to benefit smallholder farmers, including the use of seasonal forecast information for planning of crop production, but notably call for policy to better protect and restore the Nyororo wetlands to ensure they continue to provide a coping mechanism for farmers adapting to the impacts of climate change.

Burgin et al. (2025) perform a multidisciplinary analysis of expected climate change and its impacts on the biodiversity of the Central African rainforest to inform policy around its protection. The authors brought together a multidisciplinary team to collectively explore, define and review key climate and biodiversity risk messages for the region. This highlighted the importance of the Central African rainforest for both biodiversity and global climate: the rainforest is home to potentially 1000s of species new to science, boasts substantial populations of endangered great apes and forest elephants, and in places has an endemism rate of 24%; the rainforest also acts as a globally important carbon sink, accounting for 36% of tropical peat stocks. Concerningly, precipitation projections for the region are highly uncertain, with possible outcomes ranging from drying and drought to enhanced rainfall and flooding, while temperature increases and sea level rise are in line with global projections. Burgin et al. (2025) suggest that old growth forests are likely to remain resilient to climate change, but only where they are protected from additional anthropogenic stressors such as deforestation, mining and hunting. This emphasises the need for an interdisciplinary approach, protecting forests and nature in tandem.

4 | Methodological Advances

The remaining papers provide methodological advances for science at the climate-ecology interface. The first by Bottazzi et al. (2024) describes the development of the HIGHLANDER platform, aimed at improving land management practices in Italy. HIGHLANDER leverages high-performance computing to combine multiple data sources—including both climate and ecological data—process and package them. The data portal provides access to downscaled ERA5 data, historical and future climate projections, and sub-seasonal meteorological forecasts, as well as soil erosion indicators, irrigation projections, wellbeing indicators, land suitability indices for forest species and crops, milk production, IOT animal sensor data (for physiological monitoring) and fire indicators. In addition, HIGHLANDER delivers a number of use cases covering a range of common land management contexts (e.g., crop water requirements, forest monitoring and farm animal wellbeing). All data and products are provided at the national level with the intention of supporting informed decision-making by land managers and policy makers. This marks a significant advancement in the accessibility and application of climate and ecological data which has historically been prohibitively time consuming to assemble and computationally challenging to process.

The paper by Price et al. (2026) also addresses the availability and accessibility of climate and ecological data, in this instance, specifically for protected areas managers. Price and colleagues introduce the open access Wallace's pARCs dataset. The dataset contains reports for most of the world's terrestrial protected areas $>1\,km^2$ (~98,000 reports), each providing a standardised suite of information designed to aid protected areas managers in assessing climate change vulnerability and resilience. Reports include observed and projected climate variables, observed changes in land cover, observed and projected human population change, and projected changes in the climate suitability for biodiversity, assessed in terms of changes in species richness and the availability of climate refugia. Price and colleagues demonstrate the potential use of Wallace's pARCs reports for the Biebrza National Park, Poland's largest national park and home to one of Europe's largest peat bogs. The report identifies a projected increase in the risk of severe drought in the park, which Price and colleagues fear will be of significant detriment to the peat bogs. The report also highlights Biebrza National Park as amongst the least resilient to climate change globally, with significant extinction risks across taxa and widespread losses of climate refugia. These results culminate in an estimate of 'adaptation effort' required to maintain 75% of species. In the case of Biebzra National Park, Price and colleagues conclude that adaptation will become increasingly difficult above 2°C of warming and instead, park managers should consider facilitating change via restoration with climate-resilient species.

Malmborg et al. (2024) provide a holistic framework to better define model complexity. Models are ubiquitous across research disciplines and are increasingly used to understand environmental change, define global policy and prioritise mitigation and adaptation strategies. However, a lack of common terminology to describe models has thus far limited the ability to compare models, transfer models between contexts and communicate model results across disciplines. Malmborg et al. (2024) propose a framework to define model complexity, distinguishing between complexity derived from the model itself and from the (ecological) process being modelled. They suggest that model complexity is broken down into *model class complexity* (the mathematical scaffolding determining the model's overall structure and how parameters and inputs interact), *parameter complexity* (i.e., the number and nature of parameters represented in the model), *input complexity* (the number and nature of drivers and initial conditions required by the model; the spatial and temporal resolution), and *computational complexity* (the software required to construct and execute the model, the cyberinfrastructure to run it, the time needed for completion). Further, the (ecological) process being modelled should also be assessed in terms of its complexity, considering the number and type of explanatory variables. Malmborg and colleagues call on researchers to routinely and fully describe model complexity as per the above facets, arguing that this would support hypothesis generation, model selection and translation to decision-making contexts.

5 | Synthesis

This special issue highlights the importance of interdisciplinary climate-ecology research to better understand, predict, mitigate and adapt to global change. Without the consideration of both disciplines, conclusions drawn by ecologists or climate scientists working in isolation could be very different and potentially result in maladaptation and failure to sustainably mitigate the impacts of change (IPCC 2022).

Though grouped into themes above, several general points arise from papers in this issue. Firstly, we see papers predicting impacts of change in both the near- (Smith et al. 2024) and long-term (Bourne et al. 2025; Burgin et al. 2025; Cartwright et al. 2024). However, the study by Black et al. (2024) transcends these timescales, demonstrating how seasonal forecasts—in this case, of prolonged drought—might reduce the long-term risks posed by climate change.

Second, we note that two studies provide agricultural applications of research at the climate-ecology interface (Manyakaidze et al. 2025; Smith et al. 2024). Agriculture is an obvious entry point for interdisciplinary research as it is underpinned by ecological principles, shaped by specialist knowledge of production systems, and highly sensitive to climatic conditions. We now encourage research efforts to focus on other sectors which may benefit from such an interdisciplinary approach to prediction: for example, disaster risk management, socio-economic development, nature-based solutions, ecosystem restoration and biodiversity conservation.

Worryingly, when considering both ecological and climatic impacts, Mackey et al. (2025) raise concerns associated with a widely adopted climate change mitigation strategy: burning of forest biomass for energy. Mackey et al. (2025) add to a newly emerging body of literature evaluating the impacts of climate change mitigation measures and emphasise the importance of an interdisciplinary approach when doing so.

On the other hand, encouragingly, Burgin et al. (2025) and Cartwright et al. (2024) demonstrate that some resilience remains in old growth rainforests and marginal coral reefs, respectively. Both studies highlight the urgent need for protection of such resilient sites from anthropogenic pressures, such that they may act as refugia for biodiversity under future climates. More generally, there is a need for studies to consider adaptation alongside mitigation issues. The Wallace's pARCs reports developed by Price et al. (2026) demonstrate where adaptation is worthwhile and where instead, facilitation may be better placed to deliver biodiversity targets across terrestrial protected areas globally. These studies show that while mitigation is desirable, the lack of effective action on climate change means we need to be considering where adaptation approaches could prevent widescale ecological collapse.

This leads to our final point. To truly understand, predict and manage global change, society must form an intrinsic component of all research. Without consideration of climate, ecology *and* people, there will remain great uncertainty in the future of our planet. Burgin et al. (2025) eloquently illustrate this interconnectedness with an example from Gabon: Higher temperatures and reduced rainfall caused by climate change inhibit the fruiting of some tree species, representing a decline in a vital food source for forest elephants; elephants adapt by foraging on crops, but in doing so, threaten the lives and livelihoods of local communities; local communities may subsequently engage in retaliatory killing of elephants or turn to exploitative activities to compensate for crop losses; declines in elephant populations, and the vital nutrient cycling and seed dispersal services they provide, have been directly linked to the decline in a number of tree species in the Central African rainforest; changes to forest structure and composition are likely to impact weather in the region and beyond, with potential implications for global carbon cycles.

6 | Outlook

This special issue showcases significant advances in research at the climate-ecology interface. All articles highlight the importance of such advances for evidence-based decision making, including the development of early warning systems (Black et al. 2024; Smith et al. 2024) and identification of priority areas for adaptation, protection and restoration (Burgin et al. 2025; Cartwright et al. 2024; Price et al. 2026). Some have predicted the likely impacts of climate change and variability on ecosystems and their inhabitants (both human and non-human) (Bourne et al. 2025; Price et al. 2026), whilst others have demonstrated how healthy ecosystems underpin effective climate change adaptation strategies (Burgin et al. 2025; Manyakaidze et al. 2025). Finally, several methodological advances pave the way for further research at the climate-ecology interface (Bottazzi et al. 2024; Malmborg et al. 2024; Price et al. 2026). By doing so, these articles also identify a number of ways forward, including the use of novel data sources and analysis techniques, effective communication, knowledge transfer between disciplines, and interdisciplinary coordination of efforts. On this final point, we note that there are international initiatives supporting best-practice in climate-ecology research (e.g., the Ecological Forecasting Initiative, https://ecoforecast.org/), and we encourage readers to engage with such networks, including those beyond traditional disciplinary boundaries, going forward.

In sum, in overcoming boundaries between climate and ecological science, the articles in this special issue have shown that climate-ecology research provides a vital lens through which to better predict, prepare for, and hopefully mitigate the impacts of global change. The focus now should be on institutionalising interdisciplinary climate-ecology science within sustainable development research and policy, and we hope this special issue provides an impetus for that. As individuals identifying as either ecologists or climate scientists, we must recognise the value in joining forces, such that in any attempt to address a single crisis—either climate change or biodiversity loss—we might effectively address both for the benefit of climate, nature and society.

Author Contributions

Victoria L. Boult: conceptualization, writing – original draft, project administration. **Gerbrand Koren:** writing – review and editing. **Michael C. Dietze:** writing – review and editing. **James M. Bullock:** writing – review and editing. **Luke Christopher Evans:** writing – review and editing.

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Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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