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Climate Change Impacts on Species Distribution, Habitat Availability, and Conservation Priorities in Vulnerable Ecosystems

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Key Words

Climate change impacts, Species distribution, Habitat availability, Conservation priorities, Biodiversity loss, Vulnerable ecosystems, Range shifts, Species extinction risk, Climate adaptation, Conservation planning.

Abstract

Changes in the distribution of species due to climate change are causing habitat alteration, thus raising concerns about the future adequacy of current conservation infrastructure. This review focuses on the extent and nature of climate-induced range shifts, extinction risks implied by those, and the need to reconsider priorities for conservation due to the changes. A global meta-analysis revealed that species ranges had moved to areas of higher elevation at the rate of 11.0 meters per decade and towards higher latitude areas at 16.9 kilometres per decade, which is almost two to three times faster compared to previous findings, despite large interspecific variations. The projected range losses leading to extinction risks of species under mid-range warming scenarios suggested that up to 15-37% of species within sampled regions would be committed to extinction by 2050. Within topographically complex mountain systems, a combined effect of elevation range shifts and human land use creates uneven impacts, when species from lower elevations find less anthropogenically disturbed areas as they migrate uphill, while high elevation species are affected both by land use and elevational restrictions. Neither the current protected area networks nor their design principles take into account the dynamics in question. A modeling effort predicting continental-scale networks of reserves estimated high species turnover by the end of the century at many locations, leaving open the possibility that current reserve borders may no longer be effective in protecting the species for which they have been created. Overall syntheses support the view that the amount of predicted loss of biological diversity depends on the method, the group, and the geographical location used, but consistently suggests that extinction rates will lead to significantly accelerated species losses worldwide. Taken together, these facts suggest that the priority should shift from static to dynamic and topology-aware conservation efforts.

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Introduction

Species distributions are determined by the climate and, as the climate changes and global temperature rises, the distribution area of species will shift in latitude, elevation and depth in aquatic environments. Not all species show similar responses and the rate and direction of these distribution shifts depends on the taxa, life histories, dispersal capability and the physical environment of the species, and the matrix environment around many natural systems may facilitate, prevent or even stop the migration of species due to changes in climate. Due to the fact that the majority of the existing conservation tools have been developed according to the historical/current distribution of species and not according to future distributions, climate change is an issue in conservation planning not only because it decreases suitable habitat but also due to its structural nature (Zheng et al., 2026). In this review, the pace and pattern of climate-induced distribution shifts, extinction risk due to these changes and the existing knowledge on the efficacy of conservation tools will be summarized.

The Pace and Pattern of Climate-Driven Range Shifts

Firsthand observational data shows that species range shifts in response to climate change are happening at a much faster rate than previously thought and, in many instances, twice or even three times as fast. A global meta-analysis, which collected range shift information for various taxa, showed that the median distance for elevation changes is 11.0 meters per decade, whereas for latitudinal changes the median is 16.9 kilometers per decade, two and three times as fast as the previous analyses estimated (Chen et al., 2011). The same meta-analysis concluded that the distances species moved were the greatest in studies where warming was the strongest, and the latitudinal shifts were, on average, sufficient to keep up with the changing temperatures, suggesting that many species are adapting by keeping pace with the climate change. At the same time, different species move at highly variable rates based on their specific characteristics and environmental factors. An important conclusion here is that while a rate which allows one to adapt to changing climate on average is fine for some species, it may be too slow for others because this study demonstrated that the individual species' rate of movement depended on the combination of internal traits and external factors.

Extinction Risk from Habitat and Range Loss

However, translating predictions of range shifts into threats to biodiversity requires relating species distributions to the well-known association between range size and extinction probability. According to an oft-cited study employing such a framework and sampling regions representing roughly 20% of Earth's land surface, mid-level scenarios of climate warming by 2050 would result in 15-37% of species within the sampled regions and taxa being committed to extinction in the sense that their remaining ranges would be too small to maintain viable populations, even assuming a time lag before extinction (Thomas et al., 2004). Such a prediction, while uncertain depending on particular warming scenario and extinction risk model chosen, revealed climate change as a threat to biodiversity on par with – and even surpassing – habitat destruction through land use, which was considered the primary driver of species extinction risks before Zheng et al., (2026). Further synthesis research confirmed that, despite wide variability of estimates for future climate-induced biodiversity loss according to modeling method, taxonomic groups, and even choice of biodiversity loss metric employed, most modeling frameworks point to a catastrophic effect of global warming on biodiversity, with the most pessimistic projections reaching almost mass extinction levels (Bellard et al., 2012).

Complex Vulnerability Patterns in Mountain Ecosystems

Vulnerability to range loss as a result of climate change is not universal even within species living in the same general type of environment, according to recent studies that have used topographic data in conjunction with human land-use pressure on all of the major mountain ranges in the world. These results show that almost 60% of the mountainous areas in the world are under high levels of human pressure, which is largely centered around lower elevation zones and mountain bases. As such, when species move uphill in response to climate change, they often move out of areas of high human pressure and into areas of lower pressure, and in some cases end up with higher amounts of habitat than they had in their starting zones (Elsen et al., 2020). The opposite trend was observed at higher elevations, where limitations imposed by the topography, namely the decreasing surface areas on mountains due to increased elevation, further restricted the ability to gain more intact habitat despite a declining human pressure, thus posing another layer of vulnerability for high-elevation specialists, who already live in the coldest places available on a certain mountain and are the least able to colonize new areas due to the limited upslope habitat availability (Elsen et al., 2020). This conclusion is highly relevant to the search for truly endangered ecosystems because a vulnerability assessment based solely on the climate envelope may be highly misleading.

Adequacy of Existing Protected Area Networks

Given that most of the protected areas were formed based on the distribution of the species at the time of establishment, an important issue regarding prioritizing conservation involves the ability of such networks of protected areas to serve their purpose in light of changing species distributions. Species turnover, which refers to the change in species composition from the original community to a new one at a particular locality, was modeled for a continental-scale breeding bird fauna against a continent-wide set of Important Bird Areas. The results revealed that species turnover was highly variable in different parts of the region but significant for many localities, with more than half of the priority species turning over at 42% of localities by 2085 Hole et al., (2009). In essence, this finding demonstrates that whereas the size of the land in many protected areas will continue to be maintained and protected against any form of destruction or degradation, the actual combination of species in these areas may end up becoming different from those for which the protected areas were created, an important factor that should be kept in mind when measuring conservation success in future. The researchers involved in the study felt that such a scenario requires protected areas to be looked at as part of a wider approach towards conservation.

Discussion

Together, these findings suggest several convergent implications about the need for adjusting the priorities of conservation action to take into account the effects of climate change on vulnerable habitats. First, the rate at which species move their ranges to keep up with regional warming trends may be sufficient overall, but varies significantly between species, which means that assessments of potential impacts from climate change on individual species cannot make the blanket assumption that all species of interest are capable of following their moving climate niche (Chen et al., 2011). Second, the impact of range contraction on extinction probability under moderate warming scenarios is significant, and though the magnitude of the expected biodiversity loss may differ according to the methods and taxa in question, the consistency of findings on the threat to biodiversity posed by climate change suggests the need to consider it as the leading cause of extinction rather than habitat loss or any other threats (Thomas et al., 2004; Bellard et al., 2012). Third, the evidence from mountain ecosystems shows that vulnerability assessments based only on climatic suitability and not taking into account topographic area restrictions and human pressures are likely to overestimate the vulnerability of some species and underestimate it in others Elsen et al., (2020). Fourthly, evidence from protected area turnover shows that even well-designed reserves that take into consideration the present climatic situation will not suffice as time goes by because of climate change, which is why it is important to prioritize the maintenance and creation of connectivity between the protected areas to allow the species to follow the suitable habitat as it shifts, but in between the protected areas and not limited to individual boundaries (Hole et al., 2009). In totality, these results show a need to prioritize a conservation scheme that takes into account the capacity of each species to shift ranges, vulnerability assessment that uses topography, and dynamic reserve planning.

Adaptive Conservation Strategies for Vulnerable Ecosystems

Beyond Static Reserve Boundaries

Both the evidence on protected area turnover and that demonstrating topographic variability in the degree of vulnerability support a similar conclusion regarding best practices in conservation. With the establishment of reserve networks aimed to incorporate the presence of species and habitats at a specific time point, the observed rate of species turnover within the protected area network implies that even though the reserve sites would maintain their integrity and legal protection, they may host a new set of species rather than that they were designed to protect (Hole et al., 2009). This does not imply that existing reserves become ineffective in terms of their conservation potential; the same study demonstrates that the continuation of existing reserves becomes a generally relevant practice when considering changes caused by climate and environmental conditions (Hole et al., 2009). However, the results show that reserve networks should be used as part of a broader connectivity strategy rather than as an absolute solution.

Topography-Informed Prioritization

The conclusions regarding the mountain ecosystem provide a good example of the problems that may arise in the process of conservation allocation if the spatial structure of landscapes is not taken into account. Due to the fact that many species of lowland moving up are often gaining access to less disturbed and more intact habitats, conservation effort focused on these less risky movements could potentially be better spent on species of highland ecosystems facing the additional problem of shrinking land area and lack of upward refuge because of global warming (Elsen et al., 2020). This implies that conservation prioritization strategies aimed at the preservation of mountain and other physically limited ecosystems must take into account not only the climate suitability but also the relationship between the availability of land at each elevation and human disturbance, because the two factors do not always coincide (Elsen et al., 2020).

Connectivity as a Conservation Priority

From each of the four lines of primary evidence discussed above, it is evident that the idea of connectivity in response to climate-driven distribution change becomes a common thread throughout the conservation science literature. In the case of species whose distributions track their climate niche fast enough to allow them to keep up with climate change, it will become necessary to provide these species access to the new habitats. It thus becomes apparent that connectivity is a prerequisite for the ability to track the range, which has been demonstrated in observational range shift studies (Chen et al., 2011; Hole et al., 2009). In this way, the idea of connectivity shifts from an additional benefit into a basic requirement for existing reserves in terms of their effectiveness under climate change.

Conclusion

Rapid rates of species range shifts, which, while on average adequate to keep pace with regional warming trends, show considerable variation between species and result in extinction risks in the tens of percent of species by mid-century, based on even moderately conservative projections, are occurring as a consequence of climate change. Such vulnerability to species range shifts is spatially heterogeneous, influenced by the geography of the region as well as current land-use pressure and cannot be fully described using the climate envelope method, especially in montane regions where high-altitude specialists are doubly endangered. Protected areas created based on current species distributions, while expected to experience large amounts of species turnover, should adapt to meet future conservation needs that would require more dynamic connectivity-based conservation efforts.

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