Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: https://aejournals.org/

Original Research Paper

Climate Risk Mapping Approach for Identifying Future Wildlife Conservation Hotspots

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Key Words

Climate risk assessment, Conservation hotspots, Species distribution shift, Habitat refugia, climate vulnerability, Wildlife corridor conservation, Conservation prioritization.

Abstract

As predicted changes to temperature regimes, precipitation patterns, and disturbance dynamics under climate change could shift conservation priority areas away from current climate and species distribution hotspots, conventional conservation mapping strategies that focus primarily on predicting where current populations are and what habitat conditions are like under present conditions may be insufficient for assessing and predicting future conservation success. This paper outlines a Climate Risk Mapping approach that draws on species distribution, habitat suitability, climate projection, disturbance impact, and anthropogenic context data to assess likely future conservation hotspots and novel climate refugia. This framework is grounded in current work in climate risk assessment, species-range shifts, wildfire effects, hotspot analyses, threats from infrastructure, and human-wildlife conflict. The framework identifies areas that will likely remain ecologically significant in the future and areas that will become more vulnerable to degradation due to the changing climate, thereby facilitating more proactive conservation planning. Further refinement through applied conservation decisions is needed, but this framework offers a robust tool to foster climate-resilient biodiversity management in all biomes.

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Received: 25th May, 2026; Revised: 6th June, 2026; Accepted: 8th June, 2026; Available Online: 07th August, 2026
(DOI): 10.70102/AEJ.2026.18.3s.75

Introduction

The identification of priority areas for wildlife conservation has traditionally been based on mapping those areas where species richness, habitat quality, and threat exposure are greatest today, but with the rapid pace of climate change, many of the areas identified as priorities today may not be so in the next 30 years, and other areas not currently being considered may become more important in the future. The process of operationalizing climate risk assessment in a global marine warming hotspot has demonstrated that the exposure, sensitivity, and adaptive capacity of a system must be integrated into a single assessment framework to understand climate risk, and that this integration reveals significant variability in climate risk within what can be considered a single hotspot (Boyce et al., 2024). Studies that have investigated species' responses to climate change based on distribution have shown that species are already undergoing measurable range shifts in response to changing climate conditions, and that areas projected to experience stable climate conditions may be identified in advance and prioritized as refugia, even before current populations are shown to be decreasing in response to climate change (Vaissi & Mohammadi, 2024). The importance of a spatially explicit analytical framework to estimate wildfire risk to brown bear habitat and movement corridors within conservation areas has been used to show that conservation areas that may meet a species' habitat requirements can lose conservation value due to the risk of disturbance caused by climate-related changes, such as increased frequency of wildfires (Khosravi et al., 2022). It was shown that a combination of climate change prediction and existing diversity and conservation status data can help to prioritize areas based on likelihood of remaining conserved in the future, but not just current conservation status (Xia et al., 2022).

The Climate Risk Mapping Approach proposed in this paper addresses a limitation which these studies point to collectively: Operational approaches of climate risk, identification of refugia, disturbance risk assessment, and long-term priority planning have each been demonstrated in isolation, but a consistent approach to wildlife conservation planning that integrates current hotspot evidence and projected climate and disturbance risk to identify which climate-sensitive priority areas will be suitable, which will become unsuitable, and which will already be prioritized and are thereby at risk despite a changing climate has yet to be realized.

This paper makes three main contributions. First, it suggests a mapping structure that explicitly considers, not just current, but future, climate risk to conservation hotspots, where future climate projections are not simply used as an input to the process and are not treated as data for prioritization in own right. Second, it adds the concept of climate-related disturbance risk (e.g. from wildfire or other extremes) directly to hotspot assessment, acknowledging that disturbance risk can be a threat to conservation value apart from the slow process of climate suitability change. Third, it also addresses the identification of potential hotspot refuges and hotspots in the future, beyond just identifying current hotspots, as well as on status of decline or persistence.

This paper is organized as follows: In Section II existing constraints in hotspot identification techniques are reviewed with reference to recent studies on constraints in infrastructure collision risk related to hotspot identification, human-wildlife conflict related to hotspot identification and terrestrial biome assessment. The mapping methodology used to identify future risk zones is given in Section III. The methods of hotspot validation and comparisons to the existing methods are discussed in section IV. The paper is finished in Section V where directions for further validation are provided.

Constraints in Existing Hotspot Identification Techniques

The results of the research also suggest that species distribution and habitat quality based hotspot mapping methods can overlook areas of high conservation concern where high collision risk instead occurs due to the interplay between species movement patterns and human infrastructure, highlighting the need to consider both movement patterns and human infrastructure when developing hotspot mapping approaches (Gauld et al., 2022). Therefore, the critical habitat and corridor conservation prioritisation was preceded by an in-depth study of the hotspots of human-brown bear conflict in the southwestern part of Iran, revealing that areas of high habitat suitability for a species do not always overlap with areas of high conservation priority when considering human-wildlife conflict risk: human-brown bear conflict can make otherwise suitable habitat for the species and surrounding human communities impractical (Khosravi et al., 2023). Research on an ecological assessment of terrestrial biomes to determine conservation value for wildlife has revealed that the conservation value in the different types of terrestrial biomes is different, and if a hotspot technique is applied on a large scale without taking into account ecological characteristics, it may not reflect conservation values within a biome (Ansari et al., 2023).

The recent sources confirm the presence of a common set of constraints in the existing hotspot identification techniques. Research on infrastructure collision risk indicates that habitat-based hotspot mapping may not capture risk from species/human infrastructure interaction, which suggests that habitat quality-only hotspot approaches are limited. Research on human-wildlife conflict highlights that conservation priority does not always align with habitat suitability when considering the practical viability of conservation action in a specific area, suggesting that human-wildlife conflict needs to be included in hotspot mapping, alongside biological suitability. Research on the assessment of conservation value on the ground indicates that conservation value is not consistent across all biomes and that conservation hotspot techniques need to be sensitive to the context of the ecological situation in a particular biome. The collective results suggest that a climate risk mapping approach to the identification of future conservation hotspots should consider infrastructure and human-related risk factors as well as habitat and climate suitability, integrate the practicality of conservation action in areas identified as hot spots, and use assessment criteria shaped by the ecological requirements of the particular biome being assessed, not a single definition for hot spots across all landscape types.

Mapping Methodology for Future Risk Zones

Current Hotspot and Habitat Baseline Assessment

The mapping approach starts with the usual hotspot identification approach of defining a baseline set of existing species distribution, habitat quality and diversity data. It extends this baseline assessment to incorporate the ecological context of a biome, so that the definition of a hotspot is not the same over every different type of biologically distinct landscape. The baseline also includes existing corridor and connectivity information, which not only designates core habitat regions, but it also delineates the corridors or movement pathways that connect these core areas.

Climate and Disturbance Risk Projection

The methodology builds on the baseline assessment, and superimposes the expected climate risk and disturbance exposure on each identified hotspot and candidate area. Climate risk projection includes exposure, sensitivity, and adaptive capacity components, which have similarly been included in operationalizing climate risk in other conservation contexts, and disturbance risk projection includes climate-related hazards (e.g., increased wildfire frequency), that can degrade otherwise suitable habitat without interacting with the climate change process. In this stage, regions outside of the current hotspots are also considered and areas that are likely to become climatically suitable refuges in the future are identified in addition to assessing existing hotspots.

Human Interaction and Feasibility Layer

The last methodological element adds human interaction risk to the hotspot mapping process to address one of the limitations of previous studies, which found that habitat-based hotspot mapping may ignore human interaction risk stemming from infrastructure collision hazards and human-wildlife conflict. This layer marks where there is high biological habitat and/or climate suitability, combined with high infrastructure risk or conflict potential and will help identify areas that need to be investigated in more detail before being considered high priority. This layer is designed to ensure that areas that have been identified as future conservation priorities are not only biologically suitable but also practically viable as locations to support continued investment in conservation.

Hotspot Validation and Comparative Results

Anticipated Validation Outcomes

The Climate Risk Mapping Approach is not yet used to make an operational conservation decision, so its anticipated validation is based on existing climate hotspot studies. The following climate risk studies have shown that the combination of exposure, sensitivity and adaptive capacity allows for a finer distinction between risk levels in priority areas. Refugia conservation studies also suggest that early warning of population declines may be possible by identifying climatically stable areas. The proposed methodology is thus anticipated to enhance the proactive conservation planning process by identifying vulnerable hotspots as well as future refugia.

Comparison with Existing Hotspot Techniques

The proposed mapping approach offer a more predictive conservation strategy than standard hotspot mapping approaches, which rely only on the current distribution of species or habitat suitability. The framework is designed to provide more consistent long-term conservation priorities by incorporating climate projections, biodiversity status, diversity patterns and factors of human interactions. It differs from static applications in that it differentiates persistent hotspots from areas that are predicted to become ecologically unsuitable in the future due to climate change. The feasibility and disturbance factors further enhance practical conservation decision-making by highlighting those sites where conservation is more feasible.

Implications and Limitations

The proposed methodology can be used to proactively allocate resources and identify areas that need to be conserved before significant ecological changes have taken place. The assessment is biome-sensitives, allowing for a balanced prioritisation across a range of ecosystems and minimising bias due to a single hotspot criteria. The framework is dependent on the accuracy of the climate models, quality of species distribution information, and reliable information about disturbance and human interaction, however. Uncertainty may be higher in regions where ecological records are scarce or the environmental data is coarser. Further validation with actual cases of conservation planning will be needed to test robustness and enhance the applicability to practice.

Conclusion

This paper has proposed a Climate Risk Mapping Approach that encompasses the current baseline assessment of habitat and hotspots, a climate risk layer, a disturbance risk layer and a human interaction feasibility layer to identify future wildlife conservation hotspots that are expected to remain suitable under climate change, as well as identifying future refugia. The approach takes into account constraints identified in the most recent hotspot research that looked at elements unrelated to a species' distribution or habitat quality, such as ecological context, and provides a more future-oriented and practically realistic basis to allocate conservation resources than hotspot approaches that only consider current distribution and habitat quality measures. The methodology is also relevant to current conservation planning activities for a variety of taxa, biomes and climate scenarios, and there is still opportunity for further development of its human interaction and feasibility layer in the light of more infrastructure and conflict data.

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