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COMMENTARY

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Climate-driven range expansion through anthropogenic landscapes: Landscape connectivity matters

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Climate change has caused and will continue to cause significant changes in the distribution ranges of species. Poleward and upward range shifts have been reported in a variety of species in response to contemporary climate change (Lenoir & Svenning, 2015). Other types of range modifications such as range filling (i.e., colonising climatically suitable areas within its distribution range) may occur as well (Cannone & Pignatti, 2014). However, there is evidence for variable gaps between the potential range shifts to track climate change and the actually realized range shifts, often referred to as climate debt (e.g., Devictor et al., 2012). Range-restricted species with narrow niche breadths face the greatest climate change related risks, including considerable climate debts, but the issue and the consequences for species-related ecosystem functions are assessed to be of broad ecological significance (Luck et al., 2009). Strongly fragmented landscapes in highly anthropogenic regions can, for example, strongly hamper climate-related northward expansions and/or range filling. This could eventually lead to strongly disrupted regional or continental distribution ranges in the future, making it even more difficult to conserve threatened species on a larger scale.

In their paper, Hodgson et al. (2022) applied a landscape conductance approach to show the effect of habitat configuration and area on woodland moths that expanded the range at the northern, leading edge of their distribution in the United Kingdom. Their study goes beyond an approach of modelling range shifts only with climate envelopes that often ignore landscape ecological and behavioural ecological insights as suggested in Van Dyck (2012). Species range shifts ultimately result from individuals that successfully colonize vacant habitat beyond the current range edge. Colonisation in animals that are able to actively disperse is in turn the result of movement behaviour of individuals that emigrate from local populations and interact with landscape structures and hence with environmental information that will propel organisms forward or slow them down, often using particular pathways across the landscape. Hodgson et al. (2022) were able to use daily catches of the Rothamsted Insect Survey, a unique and long-running (58 years) network of light-traps, and high-resolution distribution data to empirically test both the importance of habitat amount and landscape conductance for range expanding woodland moths. Previous studies on how species could hypothetically move through fragmented landscapes mostly used virtual species and landscapes (e.g., Hodgson et al., 2016). The use of high-quality real-world data is, therefore, an important and timely next step in landscape-scale approaches for the study of variation in climate debts.

Distribution ranges of species have always been dynamic in time and space, but present-day conditions of rapid climate change in combination with highly altered landscapes are resulting in an unprecedented impact on biodiversity. Therefore, the main conclusions of this study reinforce the urgent need for conservation and restoration measures to improve landscape connectivity, aiming to reduce the probability of regional extinctions (Haddad et al., 2015). It is recommended to apply such a landscape-based approach at a wider continental scale not only on a species-by-species level, but also on species communities including different taxonomic and functional groups. However, strategic collections of essential biological information should be recognized as a methodological bottleneck, while such information is vital to forecast biodiversity changes under climate change (Urban et al., 2016). Predicting land-use changes at relevant scales and climate-dependent dispersal behaviour to predict spatial responses have been identified as two key biological mechanisms that can improve predictions of species responses to climate change.

Among the macro-moths analysed in the study of Hodgson et al. (2022) there was a bias toward woodland species. There is no a priori

This is a commentary on Hodgson et al., 2022, https://doi.org/10.1111/gcb.16220 reason why the high relevance of habitat configuration should be limited to species of this habitat type. However, there is still much to learn about how species of different habitat types vary in their ability to detect bits and pieces of fragmented habitats during dispersal movements. It is the interaction between the organism's perceptual range and sensory ecology on the one hand and the degree of fragmentation of habitat and other landscape elements on the other that will affect the functional resolution or grain at which landscapes will shape dispersal movements at different biological costs (Bonte et al., 2012; Van Dyck, 2012). Macro-moths are an interesting study group in this context as they can be monitored with fixed sampling points using traps in a stratified design. Whether woodland species are somewhat better buffered against artificial light at night compared with open habitats requires further testing. But artificial light at night is now considered a serious local driver of moth declines in anthropogenic landscapes and is potentially hampering their nocturnal dispersal (Boyes et al., 2021).

The contribution of Hodgson et al. (2022) is timely and highly relevant in this perspective. Using a spatially and temporally extensive database on woodland moths, they were able to transcend the hitherto model-based approaches regarding the importance of habitat extent and configuration for dispersal, and thus range expansion. Due to the large number of species and their occurrence in a wide variety of biotopes, moths are ideal model organisms for testing such hypotheses. By also using species of more open and more anthropogenic biotopes (e.g., urban, gardens, parks, farmland), they were able to compare landscape conductance between woodland and "farmland" moths. Woodland species expanded more rapidly when both the amount and the conductance of woodland was high in the intermittent landscape, even when the analysis did not take species-specific dispersal capacities or other life-history traits into account. It would have been very interesting to compare life-history traits of expanding moths with those of non-expanding woodland moths (cf. Coulthard et al., 2019) since conservation actions are usually much more difficult for sedentary species than for mobile species.

The importance of including landscape conductance metrics in conservation actions for climate-impacted species and by extension, habitat-specific communities as proposed by Hodgson et al. (2022) cannot be overestimated, especially in highly anthropogenic regions (Warren et al., 2021). Butterflies, more popular but regionally often species-poor, have long played an important role in research on climate-related range shifts (e.g., Parmesan et al., 1999). Moths, more illusive but much more species-rich, make Lepidoptera as a whole a very interesting, but certainly not exclusive group for studying movements under climate change through anthropogenic landscapes (Wagner et al., 2021). The application of the approach used in Hodgson et al. (2022) in heavily human influenced regions of the world will allow nature conservation to become much more spatially targeted than is the case at present. Applying their approach simultaneously on entire species communities and on a wide variety of (threatened) biotopes (e.g., heathlands, nutrient-poor grasslands) would be a highly interesting and important next step for developing an integrated landscape approach for the conservation of biodiversity under climate change.

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DATA AVAILABILITY STATEMENT

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

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