Microclimate alters the picture

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Range Shifts

Microclimate alters the picture

Predictions based on microclimate virtually wipe out the need for climate-induced range shifts. Biodiversity conservation efforts should focus on reducing the rate of microclimate change, a phenomenon our land use practices have substantially much impact on.

We have known for a while, but there was not much we could do to solve it: our predictions of how fast species would have to shift their ranges in response to climate change are way off the mark. Recent research, however, is shedding new light on the issue and revealing that our predictions of range shifts have been vastly overestimated. The key factor in this discrepancy? Microclimate.

While large-scale climate models predict drastic range shifts, the necessary shifts to track adequate climate conditions is much lower and, in fact, significantly closer to range shifts as observed in nature. In a recent study published in Nature Climate Change, Ilya Maclean and Regan Early put numbers to this conundrum, finding that microclimate models only require localized shifts into favorable microclimates, generally less than 1 km, while macroclimate models predicted major range shifts with a median of 46.5 km in centroid.

This research adds to the growing evidence that species and communities are not always responding to climate change as predicted, with delays in distribution and unexpected shifts observed (Lenoir et al. 2010, Zellweger et al. 2020). While previous studies have proposed mechanisms such as slow population dynamics, habitat fragmentation, and natural dispersal barriers (Sanczuk et al. 2022), there was one thing we were consistently lacking to fully understand these phenomena: accurate baseline climate change data. Indeed, organisms respond to microclimate change, which is often largely disconnected from macroclimate change, the factor commonly used to predict range shifts.

Microclimate

Our current understanding of climate change relies heavily on a global network of weather stations, which are designed to record macroclimate, i.e. large-scale variations in temperature, wind patterns, and precipitation, up to two meters above a flat surface. These stations are typically located in open landscapes and are meant to represent the area within a radius of 10-100 km. Meteorologists follow specific guidelines when setting up these stations in order to minimize the influence of local "noise" sources such as trees, buildings, and topographic features on the data.

However, the microclimates experienced by most organisms can be vastly different from the macroclimate recorded by these stations, due to factors such as topography, vegetation, and urban structures. As a result, many species are able to survive and reproduce in areas where the average free-air background climate may appear unsuitable, and conversely, may be absent in areas that appear suitable but have microclimatic extremes that exceed their limits.

Microclimate change

Most importantly in the story of shifting ranges, however, is the fact that the rate of microclimate change may differ significantly from the rate of macroclimate change (Maclean 2019) Moreover, the relationship between micro- and macroclimate is highly variable depending on location and local conditions (Lembrechts et al. 2020). This can result in microclimates changing at different rates than macroclimates and can affect the suitability of local conditions for certain species as the climate changes.

Maclean and Early highlight solar radiation as one example - as the climate warms, the amount of solar radiation reaching the ground remains constant, causing microclimates near the ground to warm slower than macroclimate. However, there are various other factors that can contribute to differences in the warming rate of microclimate and macroclimate, such as land use change, changes in snow cover, and reductions in precipitation. These factors can either enhance or counteract the warming of microclimates, leading to a diverse range of outcomes.

Range shifts

Theoretically, the heterogeneous patchwork of microclimates means that range shifts will mostly be slower than what is predicted based on macroclimate data alone (Zellweger et al. 2020). This is because at high spatial resolution, there will always be local microhabitats with buffered climate, where local conditions cause a slower warming than is observed on average in the macroclimatic ‘pixel’. These patches will therefore remain within the suitable climate range of species for longer.

All of that is theory, but the key strength of Maclean and Early's work lies in its empirical validation. The authors modeled the historical (1977-1995) distributions of several plant taxa using both macroclimate and microclimate data, and then projected these distributions to the present day. Their results align remarkably well with these theoretical predictions: when using microclimate data, the expected range shifts were significantly lower than when using macroclimate data, and more closely reflected the actual range shifts observed over that time period.

Conservation implications

The findings of Maclean and Early are a significant boost for the argument that incorporating microclimate data is crucial in improving species range shift predictions. While the outlook on species range shifts may thus not be as dire as previously thought based on macroclimate conditions, there are still various scenarios for how quickly these shifts will have to occur in the future. The interplay between land use and climate change creates complex feedback loops that affect microclimates differently, with urbanization and increased land use intensity significantly accelerating microclimate change (Fig. 1, De Frenne et al. 2021). Indeed, urban centers can raise the microclimate temperature of large-scale areas through the urban heat island effect, as such reducing the buffering capacity of the remaining microrefugia within them. To understand the role of these feedback loops and slow down microclimate warming, further research - and acting upon these findings - is thus urgently necessary.

However, Maclean and Early's conclusions already provide important guidance for conservation efforts: we should not prioritize long-distance range shifts and the restructuring of protected areas, but instead focus on sustaining populations of species within their current geographic range. By preserving the microclimatic buffering capacity of nature, we can help ensure that microclimates warm at a slower rate than macroclimates, contributing to biodiversity protection. This provides a tangible goal for nature managers to work towards as the climate continues to warm.

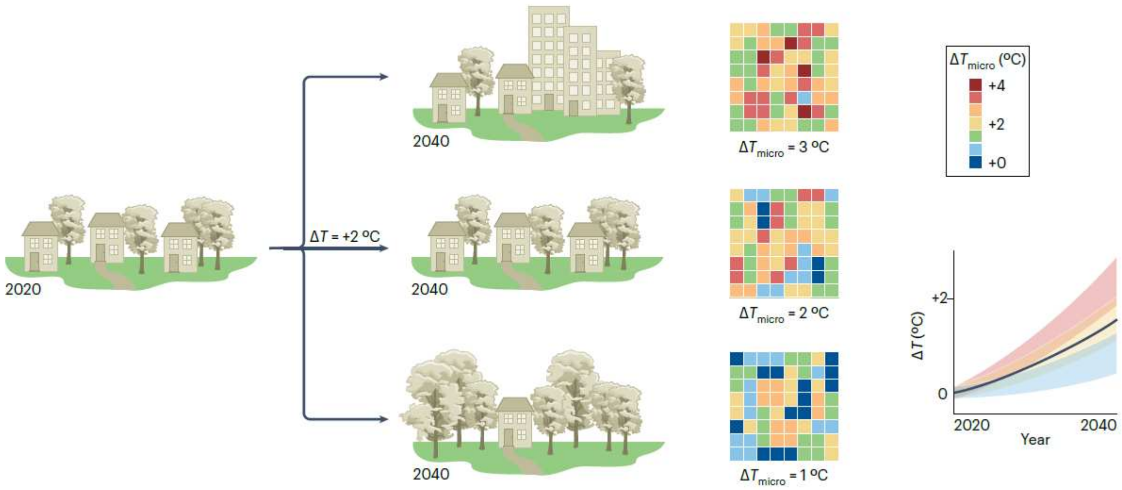

Fig. 1 | The influence of microclimate. *A hypothetical representation of the rate of microclimate change, which could result in species having to shift their ranges faster (top) or slower (bottom) than predicted when land-use change is not taken into account. The illustration shows three scenarios, with a landscape of scattered houses and woods in 2020 as the starting point. Over the next two decades, the landscape can either become more urbanized (top), remain unchanged (middle), or become less urbanized (bottom). During the same time, the macroclimate will warm by a hypothetical 2 °C (ΔT, the theoretical temperature difference between 2040 and 2020). However, each microhabitat can experience its own unique rate of warming that could be faster or slower than the macroclimate average (that is, mean ΔTmicro in each system ranging from 0 °C to 4 °C in each pixel, depending on the land use). Increased urbanization would lead to an accelerated rise in microclimate temperature, and species would therefore have to shift their ranges faster than predicted. On the other hand, an increased forestation (or additional wetland areas, for example) reduces microclimate warming, leading to slower range shifts, which can increase the chances of maintaining viable species populations. These results emphasize the importance of protecting existing natural areas and locally creating new ones, especially in urbanized settings. The graph (bottom right) shows the variation in microclimate temperature increase over the 20-year period in the different land-use scenarios (red (top), yellow (middle) and blue (bottom)) in relation to the predicted macroclimate change of 2 °C (black line).*

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