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Microclimate shifts in a dynamic world

Disparate rates of micro- and macroclimate warming forge future biodiversity and ecosystems

By **Jonas J. Lembrechts*** ***and*** **Ivan Nijs**

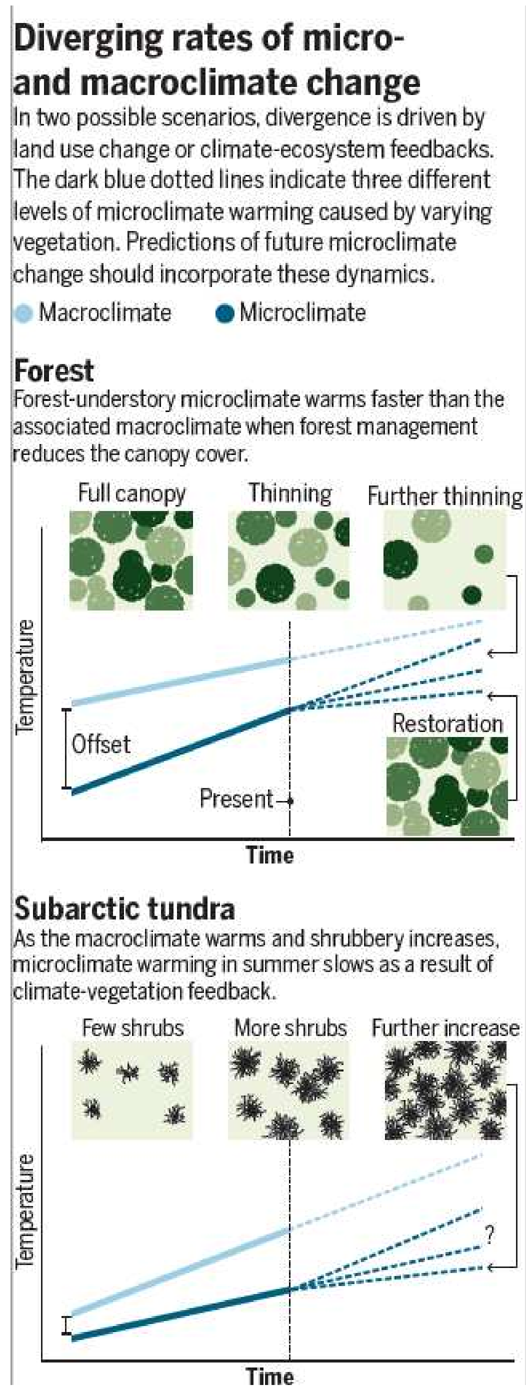
Changes in ecological functioning and biodiversity have accelerated in concert with climate warming (*1*). However, scientists base their knowledge of climate effects largely on temperature data measured in meteorological stations, which record free-air temperature (macroclimate) in controlled circumstances at more than a meter above short grassland. On page XXX of this issue, Zellweger *et al.* use modelled understory microclimate dynamics to show that macroclimate changes do not always drive the ecology of Earth's biodiversity (*2*). Indeed, the average temperature experienced by many organisms—like herbs, mosses, tree seedlings, small vertebrates, ground arthropods, and soil micro-organisms—often can differ by several degrees compared to temperatures measured in weather stations (*3*). This offset results from changes in the energy balance near the ground and is detectable at fine spatiotemporal resolutions when measuring microclimate conditions in-situ. Vertical landscape features, such as vegetation, topography, or anthropogenic structures, drive these near-ground offsets by creating micro-scale variations in exposure to radiation, wind, and humidity (microclimate) (*3*—*5*).

When assessed at high spatiotemporal resolutions, microclimatic processes operating near the ground are found not only to produce a persistent offset between micro- and macroclimates, but also to drive a different localized slope of climate change over time by decoupling local interior (i.e., microclimate) conditions from regional exterior (i.e., macroclimate) fluctuations (*6*). Although such a decoupling cannot completely isolate the local microclimate from regional macroclimatic fluctuations, it can abate or amplify the impact of regional climate warming on ecosystems (*6*).

Often overlooked until recently, however, is the additional and critical effect of temporal dynamics in landscape and ecosystem features on this divergence between micro- and macroclimate change. For example, Zellweger *et al.* show how trends in forest canopy cover can affect the warming rate on the forest floor: Understories in forests that lost canopy cover over time warmed faster than the macroclimate in recent decades, whereas understories in forests that gained cover warmed more slowly (see the figure). Strikingly, concurrent restructuring of the forest-floor plant community (for example, through thermophilisation) was related more to these microclimate changes than to the macroclimate ones.

In many of the forest systems studied by Zellweger *et al*., the changes in canopy cover originated from altered forest management (such as shifts in thinning and felling intensity). A change in anthropogenic land use is thus a key driver of microclimatic warming that diverges from the regional trend. This is also seen in urban environments, for example, where intensified urbanization boosts the urban heat island effect, in turn accelerating micro- relative to macroclimate warming over time (*7*). Divergence between micro- and macroclimate warming can also arise from feedbacks between climate change and the ecosystem itself. In cold-climate regions, for example, comparable mismatches can result from alterations in snow cover. The snow cover buffers winter temperatures in the subnivium (the seasonal microenvironment beneath the snow) and the soil underneath (*8*), and altered snowfall induced by climate change modifies these temperatures. Regions with increased winter precipitation and thicker snow covers thus experience prolonged stable subnivium temperatures, whereas regions with decreasing winter precipitation will see a reduced snowpack, advanced snowmelt, and hence, a greater number of frost days both in winter and spring (*9*).

When the net changes in temperature between winter and summer do not cancel out, the rate of microclimate warming in the subnivium will be either greater or smaller than the regional trend. Such climate-ecosystem feedbacks that drive a wedge between the micro- and macroclimate warming rates also occur in the subarctic tundra, where warming increases shrub cover (*10*). This increased shrub cover traps snow in winter and lowers the albedo, resulting in faster warming near the soil surface than in the air. The increased vegetation cover also more strongly buffers the soil and near-surface temperatures in summer, resulting in slower summer warming (*11*) (see the figure). As a final example, changes in precipitation induced by climate change will alter the coupling between soil and air temperatures. Faster warming occurs in soils that are drying out through a reduced latent heat flux (lower transpirational cooling). In wetter soils, this latent heat flux will conversely be higher, thus slowing down warming (*12*). It is thus important to realize that, in many terrestrial ecosystems across the globe, microclimates might be changing at a pace that differs from that of macroclimates.



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Although recent advances in mechanistic microclimatic modeling have proven to be a step-change in describing and predicting microclimates in the past, present, and future (*8, 13, 14*), the dynamic interactions of microclimate change with land use, vegetation, and climate change itself are far from resolved. Quantifying these dynamics—and their impacts on the slope of microclimate change—is, however, a critical prerequisite to accurately predicting species distributions and ecosystem functioning under climate change. Only with trustworthy predictions of these microclimate changes, researchers would have the necessary tools at hand to tackle the ongoing ecological crisis.

To quantify the existing spatial heterogeneity in microclimatic change and its deviations from the global spatial variation in macroclimate change, scientists need long-term time series of microclimates across all the world's biomes (*2*). Elucidating the underlying drivers— and ultimately, improving our predictions of future microclimates—requires the linkage of these in situ time series with data on land-use changes over the same time period. To this end, Zellweger *et al*. (*6*) used estimates of canopy cover based on vegetation surveys. Yet great merit can also be found in the use of increasingly detailed time series from remote sensing to effectively help quantify land use, ecosystem, and climate-change dynamics with a high spatiotemporal resolution (currently, ~20 m spatial resolution, with weekly intervals) (*15*).

A better understanding of microclimate change is standing at the crossroads of the climate and the biodiversity crisis, and is fundamental to the tackling of both. If microclimatic changes either lag behind or overtake macroclimate changes, potentially accumulating to several degrees of difference over a few decades (as shown in the new study), the fate of many ecosystems will be different from that predicted by today's models.

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