

ECOLOGY

Discovering the limits of ecological resilience

Bumble bee declines reveal species pushed to the edge of their environmental tolerances

By Jon Bridle and Alexandra van Rensburg

In 1949, environmentalist Aldo Leopold wrote that “one of the penalties of an ecological education is that one lives alone in a world of wounds” (1). Seventy years later, biologists no longer witness such wounds in solitude. Instead, millions of people on social media share evidence every day of how the behavior of a wealthy minority (2) has created unsustainable rates of biodiversity loss and climate transformation (3). Now, on page 685 of this issue, Soroye *et al.* demonstrate widespread declines in bumble bee species that are better explained by the frequency of climate extremes than by changes in average temperatures (4).

Despite increasingly precise predictions of rises in average temperatures and the frequency of extreme weather events, biologists still cannot predict how ecological communities will respond to these changes. This means that scientists cannot predict where, and at what rates of climate change, ecosystems will stop providing the rainfall, decomposition, and biological productivity on which all economies depend. Another key unknown is to what extent ongoing habitat and biodiversity loss reduces the ability of ecological communities to evolve in response to the climate crisis (3).

To determine these critical rates of biodiversity loss and climate change as well as where they are being exceeded (5), scientists test for shifts in the distribution of species over time and across their geographical ranges. Such studies reveal that the warming climate leaves a footprint: The abundances of many plant, animal, and fungal species have contracted at low latitudes and elevations, and have increased at high latitudes and elevations (6). How these responses to environmental change vary according to species’ life histo-

ries, ecologies, and their biotic interactions provides a test of which ecosystems and localities are least resilient to global change.

Soroye *et al.* used long-term datasets to assess changes in the abundance and geographical distribution of 66 bumble bee species in Europe and North America between two periods, 1901–1974 and 2000–2014. Two of their findings are especially alarming. Bumble bee populations showed substantial declines at southern (warming) ecological margins but fewer compensating population expansions

Shifts in species’ distributions in time and space vary considerably across those taxa and latitudes for which detailed data exist. For example, the physiological thermal limits of marine organisms tend to closely predict their spatial distributions, whereas those of terrestrial organisms do not. This is probably because habitat loss and fragmentation limit dispersal on land more than in the ocean (7). Surprisingly, however, the new study shows that bumble bee range expansions are just as rare in less intensively farmed landscapes

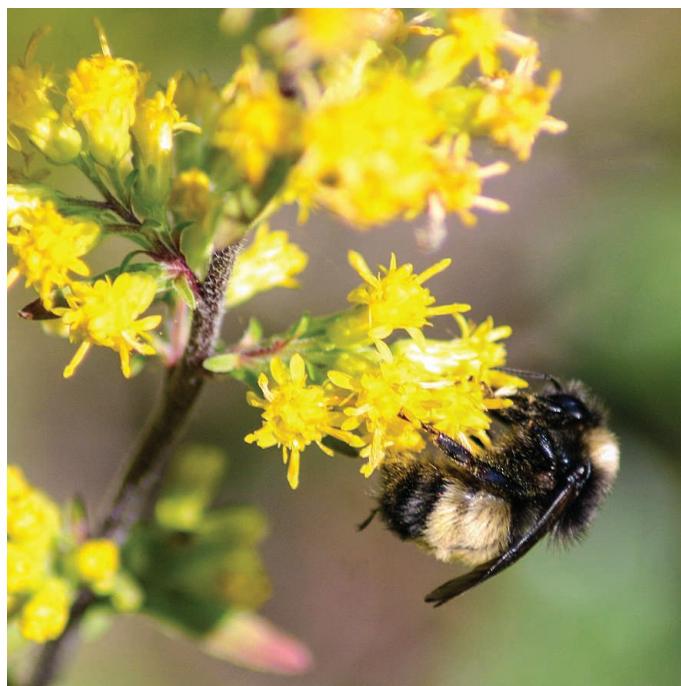
as they are in intensively farmed ones where habitat fragmentation is higher. Why range expansions in temperate bumble bees are relatively rare, even across relatively undisturbed environments, demands further investigation.

The ability of organisms to alter their behavior or the timing of key life events such as hibernation, flowering time, and germination can minimize organisms’ exposure to climate extremes. Such plasticity can slow population declines and accelerate range expansions (8). Also, many organisms threatened by warming persist by dispersing to locally cool microclimates (9). This active agency of organisms to select suitable habitats in time and space tends to increase population fragmentation at a fine spatial scale while retaining occupancy at larger spatial scales (10).

However, beyond a critical amount of environmental change—arguably similar to

that routinely experienced during a species’ history—plasticity will no longer have sufficient scope to buffer climate extremes (11). As climates exceed these critical limits, the widespread declines now observed for bumble bee species will manifest in more and more organisms and places. These declines also will be increasingly associated with extreme climatic events rather than average changes in temperature (6).

Rapid evolution could also prevent declines in population abundance and allow range shifts despite habitat fragmentation (12). This might result from natural selec-



Declines in *Bombus terricola* landed them on Canada’s “Species at Risk” list. Climate change seems to be the cause, with population declines better explained by more frequent temperature extremes rather than changes in average temperatures.

sions at northern (cooler) margins, suggesting widespread declines in bee biodiversity across both continents. Moreover, the causes of these declines apparently depend more on the frequency of extremely warm years than on increases in average temperatures. As prevailing temperatures climb closer to species’ physiological limits, extreme climate events will become increasingly associated with biodiversity loss. In addition, their effects will become more pronounced as cooler habitats, where organisms can survive unusually warm periods (e.g., deeper water, higher elevations), become increasingly rare.

tion on traits that alter organisms' physiological tolerances or their interactions with other species (13). However, the evolution of populations with different forms of plasticity (14) will be especially critical where species need to use newly informative environmental cues to decide how and when to adjust their behavior, and to coordinate their activities with those of their host and food species.

Predicting the maximum rates of such evolutionary responses demands a better understanding of genetic variation in the traits that affect fitness, as well as about how the amount of genetic variation changes with population density and with environmental shifts (12). Recent advances in population genomic analysis, combined with increasing access to museum collections for ecological and genetic analysis, are revolutionizing the field (15). For some groups of organisms, we can now integrate genomic data with environmental and demographic data to test the extent to which ecological resilience depends on evolutionary adaptation. Such data will allow researchers to estimate when and where biodiversity within a species has the power to rescue ecological communities from collapse due to climate change and habitat loss.

The new study adds to a growing body of evidence for alarming, widespread losses of biodiversity and for rates of global change that now exceed the critical limits of ecosystem resilience. However, identifying dangerous rates of climate change and biodiversity loss is only one part of the story. Political action must now follow in order to slow or mitigate these rates of global change. For how long will ecosystems continue to provide sufficient (and sufficiently predictable) rainfall, oxygen, and food, while governments ignore the economic and social costs of exceeding planetary limits? Well, we shall find out. ■

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10.1126/science.aba6432

MULTIFERROICS

Room-temperature magnetoelastic coupling

Magnetic fields alter the ferroelectric properties of a paramagnetic ytterbium-zinc complex

By Ye Zhou and Su-Ting Han

Ferromagnetism, records of which date back to the 6th century BCE, is regarded as an ancient twin of ferroelectricity, which was not discovered until 1920. Ferromagnets, which have permanent magnetic moments, and ferroelectrics, which have a spontaneous electric polarization, both have domain structures and a Curie temperature, T_c , above which materials lose their ferroic orders. Magnetoelectric coupling describes the multiferroic response of the magnetization to the electric field and the polarization to the magnetic field in the same material (see the figure). On page 671 of this issue, Long et al. (1) report magnetoelectric coupling in paramagnetic molecular ferroelectrics at room temperature, in which the responses to the magnetic field and the modifications of the ferroelectricity have the same chemical origin in a chemical complex.

Since the renaissance of magnetoelectric coupling more than 20 years ago (2), researchers have paid particular attention to the multiferroic materials. Despite extensive exploration of materials such as inorganic oxides (3) and fluorides (4), many challenges remain, mainly that the T_c values are below room temperature (typically for the magnetic order). Also, the coupling between the two ferroic orders is weak, mainly because the magnetism and ferroelectricity have different chemical origins. These problems are unfortunately intrinsic, in that they cannot be easily solved even by state-of-the-art optimization.

Long et al. have demonstrated magnetic field-induced modification of the ferroelectric domains, which is realized in a single-phase material at room temperature with a relatively low operating magnetic field. The work provides an excellent

molecular material for room-temperature magnetoelectric coupling; most previously reported couplings were observed at low temperatures or in otherwise multiphase composites (5). The finding has strong implications for the application of single-phase magnetoelectric materials from both scientific and practical points of view.

Taking advantage of molecular materials, Long et al. designed a chiral lanthanide complex, where the Yb^{3+} ion with a large total magnetic moment is adjacent to a chiral diamagnetic zinc center that exhibits ferroelectricity. They successfully demonstrated

“...the authors demonstrated magnetoelectric coupling in a paramagnetic ferroelectric crystal...”

the magnetoelectric coupling by performing piezoresponse force microscopy measurements in the presence of a direct-current magnetic field. The redistribution of the ferroelectric domains and the increase in the electromechanical response were observed upon applying a magnetic field of only 1 kOe, which is strong evidence of magnetoelectric coupling at room temperature.

The typical value of the magnetoelectric tensor component was calculated to be $\sim 100 \text{ mV Oe}^{-1}\text{cm}^{-1}$, at least one order of magnitude larger than that of BiFeO_3 , a canonical inorganic multiferroic material. The operating field was also one order of magnitude smaller than that typically required for other molecular materials. In addition, Long et al. obtained six variable polarization states by switching of the electric and magnetic fields independently. The combination of a strong room-temperature magnetoelectric coupling and the small operating field, as well as the multilevel states, provides a platform for the design of new high-density memory devices (6).

Using a series of unconventional but consistent measurements, including both the local surface displacement and structural studies (single-crystal x-ray diffraction) in the presence of a magnetic field, Long et al. showed that the magnetoelectric coupling resulted from a magnetoelastic effect. By applying a magnetic field, the

Institute of Microscale Optoelectronics and Institute for Advanced Study, Shenzhen University, Shenzhen 518060, P.R. China. Email: sutinghan@szu.edu.cn

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Science 367 (6478), 626-627.
DOI: 10.1126/science.aba6432

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