Tipping points

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Evolution alters ecological resilience

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A long-running coevolution experiment on bacteria and yeasts shows that adaptive evolution can shift the tipping points that trigger critical transitions in a community.

Anthropogenic changes impose stress upon ecosystems at rates that are unprecedented in Earth's history. One of the most concerning aspects is that ecosystems do not always respond to gradual change in a smooth manner, but instead may respond through abrupt, persistent critical transitions in their structure and function[1]. These catastrophic transitions – known as tipping phenomena or regime shifts – occur when environmental thresholds are exceeded, and cause an ecosystem to tip into an alternative stable state. Owing to the potential societal effects of such shifts, a large body of theoretical and empirical research has been devoted to investigating ecosystem resilience: the capacity of an ecosystem to absorb disturbances while maintaining its functions and avoiding tipping into an alternative stable state[2]. Writing in *Nature Ecology & Evolution*, Blake et al. provide empirical evidence that evolution can alter the resilience of ecological communities[3].

Theoretical work predicts that adaptive evolution can enhance ecological resilience by shifting ecosystem tipping points to withstand higher levels of stress[4] (Fig. 1). Empirical evidence to test this prediction has been lacking, largely owing to the challenges of manipulating natural ecosystems. Blake et al. address these challenges using a microbial ecological community in controlled conditions. They extensively mapped ecologically stable states of experimental co-cultures of *Escherichia coli* and *Saccharomyces cerevisiae* along a gradient of stress in the presence and absence of evolution. They found that coevolution affected the co-culture composition at equilibrium and its resilience, which was estimated as the system's 'potential' (a mathematical representation of the capacity of the system to return to equilibrium after being perturbed). This finding underscores the potential of evolving ecological interactions to alter the structure and functioning of a community. Then, Blake and colleagues tested how adaptation to acute stress affects resilience. They mapped ecologically stable states along a gradient of antibiotic tetracycline concentration in co-cultures before and after the evolution of antibiotic resistance in *E. coli*. Their data show that adaptive evolution broadens the range of ecologically stable states in which species coexistence is possible over the stress gradient. However, variability in species composition in this range is contingent on coevolutionary history. Their findings thus support the prediction that evolution can shift tipping points to a higher stress level and thereby enhance ecological resilience – but evolving ecological interactions can affect system variability, which may limit our capacity to predict its behaviour in the long term.

The finding that tipping points are not fixed thresholds, but that evolution instead shifts them along a gradient of stress, has major implications for ecosystem management. The hypothesized existence

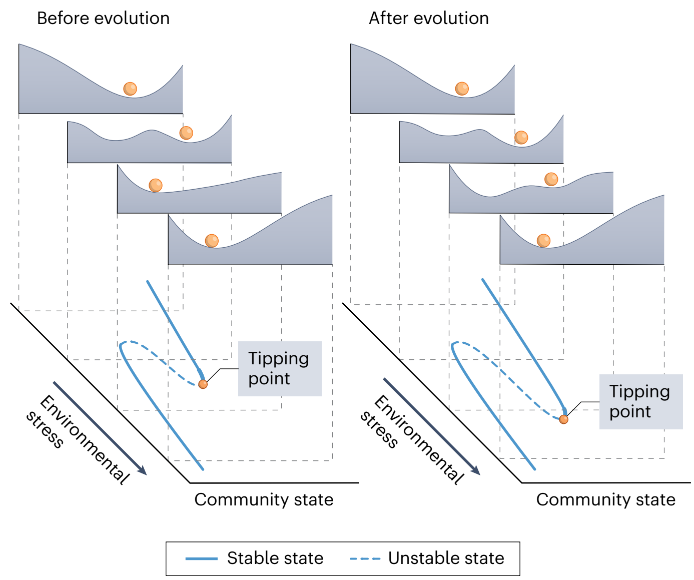

Fig. 1 | The effect of evolution on a tipping point. Blake et al. used a microbial ecological community to show that the range of ecologically stable states in which species coexistence is possible over a stress gradient is smaller before than after adaptive evolution. Hence, adaptive evolution shifts the tipping point, which enables the microbial community to withstand higher stress levels.

of critical thresholds at fixed magnitudes of stress has been a paradigm in ecological resilience research and guides policy in the fight against the global ecological crisis[5,6]. The realization that contemporary evolution causes these critical thresholds to have a dynamic rather than a static nature introduces the possibility that ecosystem tipping depends on the rate of change of stress rather than on its magnitude alone. Indeed, theoretical research has shown that a different class of tipping points (known as rate-induced tipping points) can emerge in evolving ecological systems[4]. Rate-induced tipping occurs when environmental change is too fast relative to the rate of adaptive evolution, such that the ecosystem cannot track the changing environment. Therefore, in recent years, there have been growing concern that merely setting targets for tolerable magnitudes may be insufficient, and that the identification of critical rates is required to prevent rate-induced ecosystem tipping[7,8].

Although Blake et al. do not provide direct evidence of the occurrence of rate-induced tipping, their experimental results suggest that the ingredients for rate-induced tipping may be common in ecological communities with alternative stable states. Alternative stable states have been documented in ecological communities at the core of diverse ecosystems, including coral reefs, lakes, savannahs and forests[1]. However, empirically documented examples of rate-dependent community and ecosystem responses are scarce[7]. This may be due to the fact that most empirical research that addresses community and ecosystem responses to environmental change does not consider different rates of change in the environment[9]. Rate-induced tipping – as well as other effects of evolution on ecosystem tipping points predicted by theory (for example, ref. 10) – remain to be tested. In this context, experimental communities such as the one used by Blake et al. will be instrumental in gaining critical insights into the interaction between environmental change and adaptation. These insights may help to formulate policy to address the effects of gradual environmental changes, such as climate change. By demonstrating that evolution alters ecological resilience, Blake and colleagues' study opens the exciting possibility of harnessing evolution to enhance the protection of ecosystems and the sustainable exploitation of the services they provide.

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Competing interests

The author declares no competing interests.