Community instability in the microbial world

Miniature ecosystems provide insights into general ecological principles

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From the rainforests that sequester large amounts of carbon (*1*), to the gut microbiota that help regulate digestion for the host, (*2*) ecological communities of all forms and sizes serve valuable functions. Although stable and diverse functions are more likely to be found in communities that are stable and diverse (*3*), it is unclear how exactly diversity and stability within communities influence each other (*4*). Studying this relationship in large-scale ecosystems, such as the rainforest, are often unfeasible because of practical limitations. On page 85 of this issue, Hu *et al*. (*5*) present observations of bacterial communities under highly controlled conditions. They found that diverse communities lose stability and this negative effect of diversity on stability is amplified when species in their communities interact strongly. If this applies to natural ecological communities of different scales, human activities that strengthen interactions between species may destabilize certain valuable ecological functions.

There are two different aspects of stability in ecological communities: functional and compositional. Functional stability refers to the variation in the collective function of an ecological community upon environmental changes, and compositional stability refers to the variation in the population densities of community members over time. In the face of accelerating environmental changes, finding what determines the functional stability of communities has never been more relevant (*3*). Functional stability is positively correlated with diversity, i.e. more diverse communities should lead to functional stability. The intuitive explanation is that diverse communities are likely to contain multiple species that carry out similar functions but are affected differently by environmental change, so that the function of a disturbed species can be compensated by another species. (*4*) The relationship between compositional stability and diversity is less clear and depends heavily on how strongly species in communities interact. The "competitive exclusion principle" (*6*) predicts that the number of co-existing species in a community could not exceed the number of distinct limiting nutrients. However, species within a community can increase species diversity beyond this limit through interactions. For example, one species can release partially processed nutrients that can be consumed by another species. (*7*) When interactions between species are too strong, some models have predicted that diverse communities tend to lose compositional stability and exhibit fluctuating population dynamics, (*8*) although these fluctuations can simultaneously promote species co-existence (*9*).

To put these predictions to the test, a system would need to be studied in which communities of varying diversity can easily be constructed and interaction strengths between species can be adjusted with a minimum external variation. Hu *et al.* used bacterial communities grown in controlled laboratory conditions to construct such a system. Specifically, they sought to find how the initial diversity of a community and the average strength of inter-species interactions would affect a community's final diversity and compositional stability.

Based on a mathematical model, the bacterial communities should fall into three distinct phases (see the figure). If a community starts with just a few species, or if the interspecies interactions are weak, all of its species should stably co-exist. If a community starts with more species, or if the interspecies interactions are slightly stronger, some of its species should become extinct while the remaining species should stably co-exist. And, if a community starts with even more species, or if the interspecies interactions are even stronger, more species should become extinct, and the remaining species should display heavily fluctuating population dynamics. However, these fluctuations would also slow down the rate of species extinctions.

To evaluate whether this model reflects reality, Hu *et al*. gathered a diverse collection of bacterial species, and constructed communities with different levels of initial diversity. They were able to adjust the interspecies interaction strengths by supplementing the growth medium with different amounts of key nutrients. The authors monitored population densities through DNA sequencing, and community function by estimating total biomass, over 10 days. They observed that the bacterial communities did fall into the three phases predicted by the model. The fluctuations predicted by the model manifested both in the population densities and in the total biomass. Hence, communities that were initially very diverse or very strongly interacting tended to lose both compositional and functional stability. Overall, the findings of Hu *et al*. suggest that ecological communities generally transition through distinct phases as interspecies interaction strength or diversity change, similar to how matter transitions abruptly through distinct states when temperature or pressure changes.

Human activity can transition ecological communities through phases and jeopardize valuable functions. For example, if the amount of nutrients in an ecosystem is increased because of intensive fertilization, this may increase the strength of interactions between species (*10*) and shift the community out of a stable phase of species co-existence and into a phase of compositional instability. Although this loss of compositional stability might buffer the rate of extinctions, it may be accompanied by a loss of functional stability. Therefore, reducing the amount of nutrients introduced to natural ecosystems might be one way to safeguard the many valuable functions provided by ecological communities.

Bacterial communities are attractive systems for studying principles in ecology, but it is not certain that these observations apply to communities of larger organisms. However, the author's mathematical model was not specific to bacterial communities and it predicted the three phases across a variety of community and interaction types. Therefore, the principles described here might hold for ecological communities across scales.

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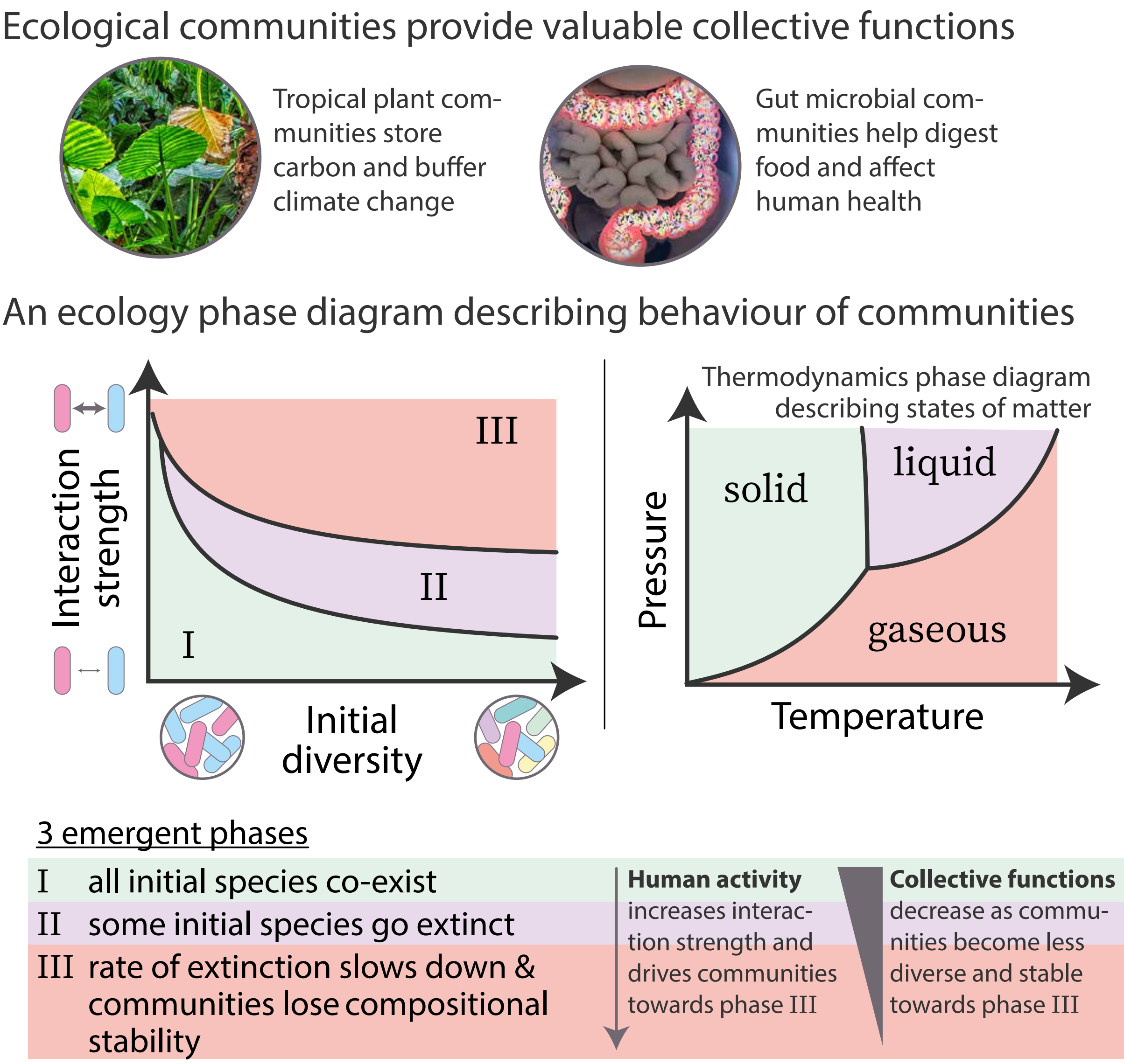

Figure 1: **An ecology phase diagram of community behavior**.

Experiments with microbial communities showed that increasing interaction strength or initial diversity drives communities through three distinct phases characterized by decreasing species co-existence and increasing compositional instability, much like water transitions through distinct states depending on pressure and temperature.