

ECOLOGY

Gini in the bottle

Shahid Naeem

An elaborate microcosm study has a message for the wider world: declining distributional equity among species, where the rare become rarer, and the dominant become more dominant, can put ecosystems at risk.

In the 1770s, Joseph Priestley, the father of biogeochemistry¹, conducted his famous experiments in which he placed mice and mint plants in bottles, and discovered the balance between 'putrefying' and 'regenerative' processes. Priestley thus began the tradition of using organisms in microcosms to explore nature. He and his colleagues clearly recognized the global significance of his findings, despite their small scale. On page 623 of this issue, Wittebolle *et al.*² describe ecological research in that tradition, but carried out with twenty-first-century tools.

Life on Earth is more than mice and mint, of course, with most ecosystems containing hundreds to thousands of plant, animal and microbial species. The balance between 'putrefying' and 'regenerative' processes in nature is better known today as the balance between respiration, decomposition, photosynthesis, primary production and many other ecosystem functions carried out by species that cycle matter between inorganic and organic forms. In the 1990s, motivated by growing concern over dramatic declines in biological diversity, ecologists began to test experimentally whether declining biodiversity — species richness — could adversely affect ecosystem functions. Early studies consisted of an eclectic mix of experiments, manipulating, for example, the richness of microbial species in Petri dishes or bottles, the richness of plant and animal species in growth chambers or artificial ponds, or the richness of plant species in grassland plots.

These investigations were surrounded by controversy, but most of them indicated that ecosystem functions, such as respiration and primary production, were indeed adversely affected by dramatic declines in biodiversity. Today, evidence that plant, animal and microbial biodiversity influences terrestrial³ and marine ecosystem functions⁴ has been documented by hundreds of studies. Such research, however, has focused on changes in species richness, in spite of the fact that changes in the relative abundance of species, or species evenness, are more prevalent and more likely to affect ecosystem function^{5,6}. Wittebolle *et al.*² now report on what is probably the most elaborate

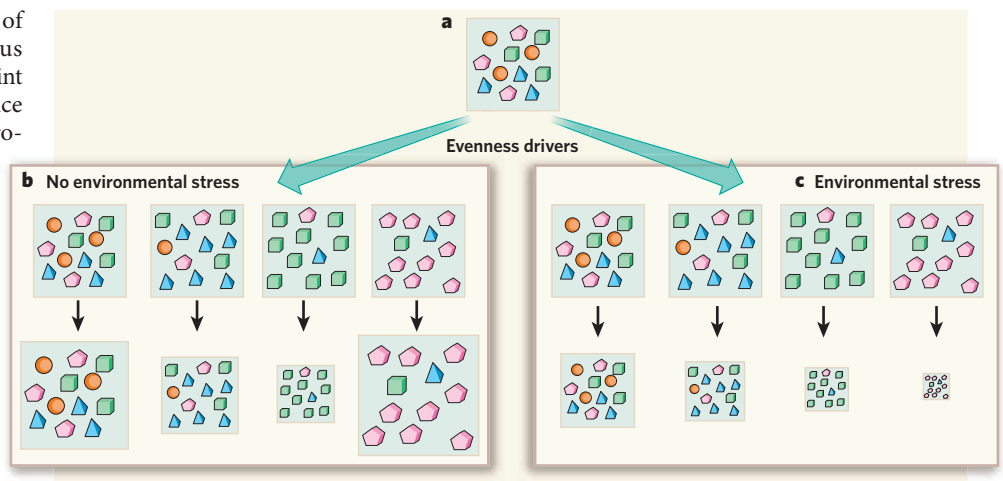


Figure 1 | Implications of Wittebolle and colleagues' results². **a**, Relative species abundances in an initial community with maximum evenness, shown by the symbols, may alter in response to 'evenness drivers'. Conservation, for example, may enhance evenness, whereas selective harvesting, species displacement by invasion, and agriculture reduce it. In consequence, ecosystem function will decrease (smaller square) or increase (larger square). **b**, With no environmental stress, highly uneven communities, such as agricultural systems, may exhibit high levels of ecosystem function, as shown by the largest square. Otherwise, a decline in functions accompanies declining evenness. **c**, Environmental stress, such as a change in temperature, pH or salinity, reduces ecosystem functioning with increasing severity as evenness declines. The smallest square depicts a system in which the dominant species was the most sensitive to the stress, and stress-resistant species were rare.

microcosm study ever conducted to examine the influence of biodiversity on ecosystem function. It is devoted entirely to evenness.

Manipulating richness is logistically challenging but straightforward; manipulating evenness is not. To manipulate richness, one constructs replicate ecosystems that vary in numbers of species while holding the total number of individuals constant and distributing individuals equally among species. For example, in an ecosystem that could be made up of three species totalling 300 individuals, one would manipulate richness by constructing replicates that contain 300 individuals of a single species, or 150 individuals each of two species, or 100 individuals each of three species. In contrast, to manipulate evenness, distributional equity is varied. Thus, with three species, one would construct replicates containing 100, 100 and 100 individuals (known as perfect equity), 99, 99 and 102 individuals, 98, 99 and 103 individuals, and so on until

reaching 1, 1 and 298 (near perfect inequity). As such a complete experiment is not practical, a set of replicates is instead constructed that represents a comprehensive, unbiased sampling of possible abundance distributions. How to construct such a set is a considerable challenge in the study of evenness. Wittebolle *et al.*² found an elegant solution based on a widely used metric of distributional equity; nevertheless, implementing it still required a staggering 1,260 microcosms.

There are many metrics of evenness, each of which has its pros and cons⁷⁻⁹. Of these metrics, Wittebolle *et al.* chose the Gini coefficient (G), whose virtue is that it is based on the Lorenz curve, a graphical representation that neatly describes distribution equity as the relationship between the cumulative proportion of species richness and the cumulative proportion of species abundance. Every community's relative abundance can be described by a Lorenz curve; G is simply the area of the region

bounded by this curve and the straight-line diagonal describing perfect equity (see Fig. 3 of Wittebolle and colleagues' Supplementary Information²).

Rather than mice and mint, Wittebolle *et al.* used bacterial species, which meant that their microcosms could be small — indeed, as wells in microplates, they were *very* small. Each well contained 18 denitrifying species (largely proteobacteria), at densities of 10⁷ per millilitre. Denitrifying bacteria metabolize nitrates and nitrites, and the level of denitrification provided a measure of ecosystem function. With the aid of modern tools to assess net denitrification, such as flow cytometry, ultracold freezers, robot pipettors and spectrophotometric microplate readers, the microplate system made exploring evenness possible at a level of thoroughness simply unimaginable by more typical ecological methods.

The thoroughness of this study² makes its results rather convincing. The authors found that declining evenness affects ecosystem functioning in much the same way as declining richness does. But the magnitude of the impact depends on the nature of the stress the ecosystem is experiencing and the functional traits of the dominant species (such traits are the properties that govern how species respond to or affect their environment), in this case² tolerance to cold or salinity; Fig. 1). For example, no bacterial species fared well when microcosms were exposed to cold stress. When exposed to salinity stress, however, some species were more salt tolerant than others; thus, microcosms with greater evenness were more likely to have enough salt-tolerant individuals to assure net denitrification.

These findings do not mean that we should run out and increase species evenness. Natural ecosystems are typically uneven, but the real world is highly heterogeneous, spatially and temporally, unlike the highly controlled conditions of this study. In the real world, different species will naturally dominate in different places and at different times, so the potential value of rare species is missed in studies where conditions do not fluctuate. There is also a growing literature suggesting that the richness and evenness of functional traits¹⁰ are more relevant to ecosystem functioning than species richness and evenness. What mattered in this study, for example, was the diversity of stress-tolerance traits, not the species diversity. The real world is also trophically complex, making one wonder what the results might have been if viruses or microflagebrates that prey on the bacteria had been present. These are directions future research should take; but as the level of detail in the authors' supplementary material illustrates, to do that will be daunting.

Do we need to go much further, however, before delivering the clear message of this research? Wittebolle and colleagues' study is technically sophisticated, abstract and small in scale. Nonetheless, the implications are global, much as Priestley's message about

the balance of nature was more than two centuries ago. Ecosystems worldwide are becoming dominated by one or a few domesticated or invasive species¹¹. So it seems likely that ecosystem functions and the services they provide are becoming less and less resilient to the stresses, such as climate change, nitrogen deposition and salt-water intrusion, that are being generated by the world's rapidly increasing population. ■

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SOLID-STATE PHYSICS

Spin's lifetime extended

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Electrons in semiconductors are subject to forces that make their spins flip. According to new evidence, if an ensemble of spins curls into a helix, the collective spin lifetime can be greatly enhanced.

Over the past decade, electron spin — the electron's intrinsic rotation, which is commonly described as 'up' and 'down' and which gives rise to its magnetic moment — has come to the forefront of research in solid-state physics. A whole new field, called spintronics^{1–4}, has emerged as an umbrella for both applied and fundamental research on spin transport and spin control in metals and semiconductors. On the applied front, spintronics is already realizing its potential in applications such as magnetic read heads in computers' hard disks or magnetic random-access memories that are non-volatile — that is, they can retain information even when the power is turned off. On the fundamental side, the field is generating equally fascinating discoveries of spin phenomena. One such discovery, the realization of a 'persistent spin helix' in a semiconductor is reported by Koralek and colleagues⁵ on page 610 of this issue.

Spin is an intrinsic property of the electron that never goes away. But unlike the electron charge it has two possible values, positive (up) and negative (down), which are linked to the spin-axis orientation. This means that the net spin of an ensemble of electrons can decay. Start with an ensemble of spin-up electrons and in a nanosecond or so you may find that they are equally 'up' and 'down', resulting in an ensemble that has no net spin.

In semiconductors, the major cause of spin decay is a rather weak, and up to recently underappreciated, quantum interaction called spin-orbit coupling. This interaction couples the electron velocity (orbit) with the electron spin. The electron velocity changes randomly when the electron moves past imperfections in the semiconductor's crystal structure or changes simply as a result of atomic-lattice

vibrations. Because of spin-orbit coupling, the spin orientation of the electron changes as well. But only a little: the electron needs thousands or even millions of velocity kicks, depending on the semiconductor, for its spin to flip and erase the memory of its original orientation.

In spintronics applications, long — tens to hundreds of nanoseconds — spin relaxation times (the time it takes an itinerant electron to flip its spin) are desired to preserve the information encoded in the spin as electrons travel through spintronic devices². To inhibit spin relaxation as much as possible, we could envisage eliminating crystal imperfections and atomic vibrations, but this would be a quixotic exercise in fighting the laws of thermodynamics.

In their experiment, Koralek *et al.*⁵ focus on spin-orbit coupling instead. Although such coupling cannot be switched off, it can be tailored by tuning the underlying spatial anisotropy of the semiconductor quantum well — a thin layer of semiconductor material (in this case, gallium arsenide sandwiched between two layers of another semiconductor), which restricts the movement of electrons in the dimension perpendicular to the plane of the layer. The quantum well's spatial anisotropy discriminates between two possible spin orientations in the plane of the quantum well. Because of spin-orbit coupling, this anisotropy is reflected in an anisotropy of spin relaxation⁶, which has been explored in a spectrum of themes, from spintronic devices⁷ to the propagation of plasmons (quanta of electronic plasma oscillations)⁸.

By tuning such spatial anisotropy and by curling electron spins into a helical wave of a certain wavelength and pitch, Koralek and colleagues demonstrate that spin relaxation