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Biodiversity–ecosystem function relationships on bodies and in buildings

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Abstract

Biodiversity underpins the function of ecosystems. Here we discuss how biodiversity–ecosystem function theory could apply to our bodies and buildings, outline practical applications and call for further research.

A key thrust of ecological theory and experiments over the past 100 years has been the study of the effects of biodiversity on ecological functions. Based on hundreds of studies we know that biological diversity can help to prevent species invasions¹ and make ecological systems more resistant to climate change fluctuations² and pathogen establishment³. Greater biodiversity can also lead ecosystems to be more productive or efficient⁴. Yet, this research has not been adequately translated to practical application. This is particularly true in the contexts most immediate to daily human lives, namely on bodies and in buildings.

It is not that we do not manage biodiversity on our bodies or in our buildings. We make decisions that influence the biodiversity around us every day. But, those daily actions are almost exclusively meant to reduce biological diversity. As a result, insights from ecological theory regarding the values of biological diversity and their underlying mechanisms, if applicable to these realms, may lead to new recommendations for the management of the life around us, recommendations that differ considerably from current practices.

Biodiversity and invasion

Outdoors, in grasslands and forests for example, high-diversity communities are typically less vulnerable to local biological invasions than low-diversity communities^{1,5}. More diverse

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Competing interests

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communities also can allow microbial communities to resist invasion on our bodies and in our buildings (Fig. 1).

In thinking about bodies and buildings, pathogens are akin to invasive species. The extension of theory developed in non-human systems to humans would predict that, in general, the more microbiologically diverse bodies, homes or hospitals are, the less likely they are to be invaded by and overrun with pathogens. It also suggests the hypothesis that the more closely related a pathogen species is to species already present in the established community, the less likely it is to be competitive in the available niche and reach a biomass that poses a health risk^{6,7}.

Empirical cases of pathogen colonization in line with the expectations of biodiversity-resistance theory are not new, but they are seldom mentioned in the biodiversity–ecosystem function literature or considered in light of its insights. In the 1960s, for example, a study⁸ found that babies whose noses and belly buttons were already colonized with non-pathogenic strains of *Staphylococcus aureus* were less likely to be colonized by the pathogen *S. aureus* 80/81. Furthermore, the authors demonstrated that newborns experimentally colonized with ‘native’, non-pathogenic strains of *S. aureus* resisted invasion of the pathogenic strains of *S. aureus* via what ecologists would call priority effects and competitive exclusion. More recently, researchers have found that antibiotic treatment, which reduces diversity and alters microbial functioning, is a major risk factor for colonization by the healthcare-associated pathogen *Clostridium difficile*^{9,10}. Restoration of gut biodiversity via faecal transplants or microbial community ‘cocktails’ has been highly successful for treating infection and preventing recurrence^{10,11}. Individual strains alone cannot induce recovery¹¹, however, indicating that at least some amount of functional diversity is necessary. Despite such evidence that diversity may contribute to preventing pathogen colonization on and in humans, the question of whether the inherent diversity of the microbial community, rather than the identity of the species present, influences the ability of the pathogens to invade has not been explicitly tested.

Another context in which biodiversity might be beneficial in preventing pathogen outbreak is in water systems. All water that enters homes contains life, typically bacteria, fungi, nematodes and even crustaceans¹². Some of these species can be harmful to humans, including non-tuberculous *Mycobacterium* species (NTMs), which are opportunistic pathogens and can be found in biofilms on shower heads. Recent research concludes that NTMs are most common where chloramides are persistent in water systems, and where biodiversity is reduced¹³. NTMs have even caused some hospitals that frequently treat water supplies with chloramides to have to use bottled water for all patients and during surgery¹⁴. Theory would suggest that fostering diversity may help combat NTMs. Indeed, showers with plastic tubing, which is partially biodegradable and hence favours microbial growth and potentially competition, contain fewer NTMs than showers with metal tubing¹³.

In general, we suggest that more empirical studies of biodiversity-invasion phenomena on bodies and in buildings, particularly in homes and hospitals, may be rewarding. In comparison with grasslands or forests, human skin and guts are systems in which insights that are gained can be directly and readily applied. We imagine that interventions aimed at

managing the biodiversity on skin and in guts are radical, but they are no less so than the interventions we carry out every day, most of which tend to reduce the biodiversity of these systems, such as the daily application of antiperspirant, which has strong and persistent effects on the composition and biodiversity of skin microbes¹⁵. Although more research explicitly testing such assertions is necessary, we suspect that these daily manipulations are often likely to be to our detriment.

Multitrophic biodiversity

Diversity might repel pathogens and reduce the risk of outbreak through competition, associational resistance and dilution. But the effects of diversity might also relate to the diversity of predators and parasites able to control populations of invasive or outbreak species. There is increasing evidence for the significance of multitrophic biodiversity and interactions in driving ecosystem functions¹⁶.

In human bodies, bacteriophages have been found to contribute to bacterial mortality as well as their evolution¹⁷. They have also been used successfully with phage therapy to treat bacterial infections¹⁸. The eukaryotes of the microbiota are less well understood but can be common¹⁹ and can play an important role in human ecology beyond infection²⁰.

The concept of trophic diversity has obvious applications in the context of our houses. Houses have recently been shown to host thousands of different species of arthropods²¹. A minority of these arthropod species are real pests with negative consequences for humans, such as bed bugs, mosquitoes that vector pathogens, or house flies, which can carry pathogenic faecal–oral microbes to humans and human food. Such pests may be better controlled where multitrophic diversity is higher. For example, recent research has shown that some spider species can prey heavily on mosquitoes that vector malaria or dengue and, in doing so, reduce their abundance²². In addition, parasitoids of various cockroach species, such as wasps that lay their eggs in cockroach egg cases, have been shown to be common in some homes²³. The occurrence and potential effects of these predators, parasitoids and pathogens on indoor pests suggests that the biodiversity in homes might reduce the chances of pest invasion and outbreak. It is possible that similar phenomena are occurring with regard to bacteria or fungi. There seem to be no studies of bacteriophages in homes or hospitals, even though such phages have the potential to play a large role in mitigating infection, and phages in water systems play a key role in reducing the abundance of water-borne pathogens such as *Vibrio cholerae*²⁴. Overall, it seems possible that greater multitrophic diversity is likely to be associated with fewer pests, pathogens and outbreaks in homes.

Biodiversity and multifunctionality

Biodiversity–ecosystem function studies have shown that the significance of biodiversity increases as more functions (hence ‘multifunctionality’), as well as spatial and temporal contexts, are considered^{1,25}. To effectively assess the value of such multifunctionality in our daily lives, a necessary first step is to understand the functions themselves. In the gut, functions tend to be metabolic, although microbiota also greatly impact immune

functioning²⁶, host development²⁷ and even host behaviour²⁸. In general, there seems to be an association between diet diversity and the diversity and multifunctionality of gut microbes²⁹. However, to our knowledge no studies have intentionally manipulated the diversity of functional roles played by gut microbes to understand their effects on, for example, the rate of digestion or the nutrients provisioned by those microbes to the host³⁰. Furthermore, we are unaware of studies that jointly consider multiple aspects of beneficial functioning to the host, such as carbohydrate fermentation and colonization resistance in the gut, to determine if they are synergistic or conflicting.

On the skin, microbes mediate many functions including defence³¹ and signalling³². It is unknown, however, whether more diverse skin microbes are better able to carry out these diverse functions simultaneously. Similarly, in our homes and hospitals, it is possible that more diversity leads to more multifunctionality and that, despite potential trade-offs among some functions, such multifunctionality is beneficial.

Conclusions

We have barely scratched the surface with regard to the predictions the biodiversity–ecosystem function literature offers concerning the species around us. Rather than exhaustively suggesting such predictions, we hope to inspire others to help connect the biodiversity–ecosystem function literature with a series of contexts in which it might actually be applied. This application is important if for no other reason than that the vast majority of our daily actions to control the life around us are the exact opposite of what the biodiversity–ecosystem function literature would predict are wise.

As a caveat, and for a bit of context, it is also important to note that the same biodiversity–ecosystem function literature that has revealed the many ways and contexts in which biodiversity can be valuable to ecological functions, has also revealed that there are contexts in which it is not valuable^{5,33,34}. We do not yet know in bodies and buildings which situations these might be. In buildings, we hypothesize that one such circumstance is in the context of cases in which individuals are immunocompromised (as is often the case in hospitals) and hence susceptible to negative effects both of pathogens and of species that are ordinarily innocuous. In addition, in other cases the unusual composition of species may turn general rules on their head. Studies outdoors have recently found that in simplified environments the effects of biodiversity can be reduced, idiosyncratic, or even negative^{5,33,34}. This means that by altering and simplifying our environments, we may not only reduce biodiversity, but also compromise or alter its potential to enhance functions^{33,35}. It may, in this light, be much more effective to conserve biodiversity in neighbourhoods, on bodies and in buildings (or in biodiversity banks; <http://microbiomeconservancy.org/>) than it is to try to restore it once it is lost. We do not know. In the end, although many thousands of studies have considered the value of biodiversity in ecosystems, that value in the ecosystems most immediate to our own lives has only just begun to be explored. When it is, undoubtedly there will be surprises. Surprises, we argue, best interpreted in light of ecology and an understanding of biodiversity.

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Fig. 1. Examples of sites where pathogen invasion is stymied by diversity in and around us.
Credit: Lauren M. Nichols and Neil McCoy