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POLICY BRIEFS

How biodiversity loss affects the health of ecosystems

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Introduction

Do ecosystems require a rich diversity of species in order to remain healthy? The question is important for policymakers, as a positive answer would mean that the conservation of biodiversity, and in particular the protection of a high number of different species, should be a high priority for all those concerned with maintaining healthy ecosystems.

The UN Convention on Biological Diversity declares that biodiversity – the biological and ecological diversity of plants, animals, and microbes – is important "for maintaining life-sustaining systems". This statement is based on the observation that areas of land that are rich in clean water, fertile soils and productive forests are also rich in species. It follows that their degraded counterparts – polluted, infertile and unproductive areas of land – generally have a relatively low number of species. In other words, that biodiversity must be an integral component of life-sustaining systems.

But does biodiversity itself lead to clean water, fertile soils and productive forests? Or does it simply flourish under such conditions? To put it another way, is the loss of biodiversity simply a symptom of unhealthy ecosystems? Or is it this loss that causes ecosystems to be unhealthy?

Since the Convention was signed in 1992, ecologists and environmental researchers have become deeply divided over the issue. A consensus, however, has gradually emerged: researchers now agree that a well-functioning ecosystem capable of sustaining life does indeed require a high level of biodiversity.

Precisely what those levels are, however, or just how much biodiversity is needed to ensure that ecosystems are healthy and life-sustaining, is still the subject of considerable debate in the ecological community. Its outcome has important implications for the policymakers who are seeking to devise and justify policies aimed at preserving the complex web of ecosystems that support life on earth.

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Why are ecosystems important?

The word 'ecosystem' is a contraction of 'ecological system', and refers to the way that nature can be viewed as a system or, according to the Merriam-Webster Dictionary, a "regularly interacting or interdependent group of items forming a unified whole". A forest is an example of an ecosystem, as is a river delta.

A wide range of the benefits of nature are attributable to the workings of ecosystems. They include soil fertility, soil retention, water quality, food production, the degradation of pollutants, flood regulation, pollination and the regulation of insect pest populations by natural predators such as spiders and wasps.

Some ecological economists have even tried to put a financial value on such 'economic services'. Robert Costanza and colleagues at the Institute for Ecological Economics at the University of Maryland, United States, for example, have placed the global figure at between US$17 trillion and US$54 trillion (at 1994 rates), suggesting that the value is the same order of magnitude as the world's economic output.

But we hardly need economists to tell us that the healthy functioning of the global ecosystem, and the individual ecosystems that make it up, are essential for the well-being of humanity. And that makes it all the more important to understand the role that biodiversity plays in the way ecosystems operate.

Research into biodiversity and ecosystems: what we have learned

There are between 10 million and 100 million species on the Earth. Most ecosystems contain hundreds to thousands of species. For any one ecosystem, these species can be divided into one of three so-called 'functional groups', based on whether they *produce*, *consume* or *decompose* organic matter, the source of energy for living organisms.

Every working ecosystem needs at least one species from each of these functional groups if it is to process energy effectively. But is it sufficient for an ecosystem to have just one species from each group (for example, a plant, a herbivore and a decomposer, such as a bacterium)? Or does a healthy, functioning ecosystem require all of the hundreds to thousands of species that we typically find?

This question is similar to asking whether a computer needs all the parts that we see when we take off its cover. One basic approach, which can apply either to ecosystems or computers, is to divide each into its many component parts and then put them all together again in various configurations in order to see what happens. Such a process has a number of functions. It helps us to understand how the parts relate to one another, to identify how they each help the overall system to work, and to establish which components are more important.

Several laboratory and field-based biodiversity experiments have used this approach. Much of this research has focused on the behaviour of systems made up of plants, which are easiest to manipulate. But there are an increasing number of studies of systems that include animals, microbes and even combinations of all three types of organism.

Three ecosystem models

One of the goals of such research is to compare the relative claims of three different models that explain the relationship between species and ecosystems. The first of these is the 'redundancy model', which postulates that the actual number of individual species is less important to a working ecosystem than the presence of all functional groups.

Such an approach predicts that if a functional group loses a species, other species within that group will increase in number to take its place. For example, if the number of wildebeest decreases, other members of the herbivore functional group will increase in number. This hypothesis therefore suggests that species-poor versions of ecosystems should work just as well as their species-rich counterparts, provided that an appropriate combination of functional groups always exists.

The second model, known as the 'idiosyncratic model', maintains that although the number of species *does* affect how an ecosystem works, the way in which this happens is unpredictable. This model is based on the idea that if you remove species from a complex ecosystem, it is impossible to predict what will happen; the system may work better, get worse, or show no change at all.

It is already known, for example, that in certain ecosystems, there are species – known as 'keystone' species – whose loss dramatically alters the ecosystem's properties. Other ecosystems, however, are known to have lost species without showing any change.

Finally, the 'complementarity model' says that the number of species does play an important role in the way an ecosystem works, as different species contribute to ecosystems in complementary ways. Plants with shallow and deep roots, for example, produce more biomass when they grow together than either plant can produce alone. Complementary species are therefore more effective in using resources, which implies that ecosystems work better when such species are present.

The first experiment on biodiversity and ecosystems

The first experiment designed to examine these three models was carried out at Imperial College London, in the early 1990s. Sixteen terrestrial ecosystems were housed in identical chambers, each occupying an area of one square metre. Each chamber had exactly the same amount of soil, water, light and rainfall. The only variable was the level of biodiversity, with chambers containing varying numbers of plant and animal (earthworms, insects, molluscs and other invertebrates) species. The researchers also separately planted a number of random combinations of the plants that were used in the main experiment.

This trial was the first to demonstrate that even if all environmental factors are held as constant as possible, simply changing biodiversity is sufficient to significantly alter ecosystem functioning. For the researchers found that varying the quantity and mix of species did indeed affect key ecosystem functions, including carbon dioxide flux, plant production, and soil nutrient and water retention.

Furthermore, although not all ecosystem functions showed the same kind of response, the data collected on carbon dioxide flux and plant production best fitted the complementarity model – namely, that a loss of species led to reductions in ecosystem processes due to fewer synergies between the different species.

An emerging consensus – and points of disagreement

Since those first experiments were published, dozens of experimental and theoretical studies have been performed around the world. Perhaps the most significant have been the grassland biodiversity experiments carried out by David Tilman and colleagues at the University of Minnesota, as well as the BIODEPTH grassland experiments in Europe led by Andy Hector (formerly of Imperial College London) and colleagues. These have confirmed that the positive effects of biodiversity observed initially under small-scale conditions are also seen when using a much larger variety of species, and conducted over much larger scales.

Additional studies have examined how ecosystems are affected by diversity in aquatic insects, microbes, zooplankton, wetland plant species and soil fauna, for example. These improved upon the original experimental design, using more combinations and types of species, working outdoors under more natural conditions, using larger plots, conducting experiments for longer periods, and using an increasingly complex and sophisticated array of analytical methods.

Their findings have been mixed. Some have shown that changes in biodiversity could significantly affect the workings of ecosystems. Others have shown no significant response. As a result, drawing overall conclusions from the results has not been easy. Nevertheless, a consensus is beginning to emerge along the following lines of argument:

- First, that history, geography and local climate are the primary factors governing how an ecosystem performs; biodiversity plays an important – but secondary – role.
- Secondly, that changes in biodiversity – such as the loss of dominant or 'keystone' species, the loss or addition of complementary species, or the addition of invasive species – can affect how an ecosystem works, and that while some of these impacts can be predicted, others cannot.
- Finally, that disruption to an ecosystem can often be reduced by maintaining biodiversity as closely as possible to its historical levels.

This consensus contains elements of each of the three original models – namely redundancy, idiosyncracy and complementarity.

Moving beyond numbers

If biodiversity matters to the environment, as the experience described above appears to confirm, what are the implications for policy, management and conservation?

Researchers and policymakers who deal with biodiversity issues are primarily concerned with cataloguing, and subsequently conserving, individual species. These are often found in what are called biodiversity hotspots and other areas where species diversity is high. Our new understanding of biodiversity and ecosystems, however, suggests that we need to shift the emphasis away from simply cataloguing species richness to understanding what is called 'functional diversity'.

Merely cataloguing species is a gross, but relatively uninformative, measure of biodiversity, in the same way that body temperature is a gross measure of an individual's health, but doesn't tell us much about what is wrong when the temperature is too high. Such measures are important indicators, and can certainly serve as warnings when something is amiss. But they cannot be used by themselves to prescribe solutions. Just as doctors do not prescribe medicines solely on the basis of an anomalous body temperature, meaningful environmental policy measures cannot be based solely on dramatic declines in species richness.

This is where 'functional diversity' comes in. Functional diversity is a measure of how an individual species contributes to the workings of an ecosystem – for example, whether it enhances soil fertility by facilitating the fixation of nitrogen, whether it can tolerate drought or reduce soil erosion, or whether it is combustible and therefore more likely to increase the probability of fires. Functional diversity provides a better insight into the relationship between biodiversity and environmental processes than just the number of species in a given area.

Research in measuring functional diversity is still in its early stages. As a first step, scientists assume that the number of species in an ecosystem correlates with the overall functional diversity of that system. Current evidence supports this assumption – the more species you find in an area, the greater the functional diversity is likely to be. Conversely, if biodiversity declines dramatically, then functional diversity will almost certainly decline as well.

This suggests there will always be an important role for cataloguing species richness, which serves at least two purposes. First, it tells us when stop-gap measures need to be taken, as a dramatic decline in species richness suggests the need for strong species preservation, or for sustainable-use policies.

Secondly, species richness can serve as a proxy measure of functional diversity when functional diversity itself cannot be measured. In a typical rainforest, for example, there might be 300 species of trees per hectare and 3,400 species of beetles. And in a single gram of soil there could be around 4,000 strains of microbes. In practical terms, it is unlikely that scientists will be able to assess the contribution of each species to the overall functional diversity of the ecosystem, but just counting the number of species will give an approximate guide.

Nevertheless, focusing on the functional diversity of an ecosystem, and the contribution to it of each individual species, provides an important new approach to understanding the critical issue of the relationship between biodiversity and ecosystem health.

The challenge to policymakers

The consequences of biodiversity decline – whether occurring locally, regionally or globally – are complex, and our understanding of the reasons for such decline, where it is observed, is still in its early stages.

Governments, non-governmental organisations and academic institutions are currently investing a large amount of money and human resources in efforts to catalogue biodiversity. Strengthening taxonomy is certainly a critical step forward, similar to the way in which sequencing the human genome is the first step towards fully understanding the genetic basis of disease.

But just as remedies for some diseases will come from understanding both the role of individual genes *and* the interactions among them, remedies for some environmental problems will require an understanding of both the functionality of individual species and of their interactions. In other words, understanding the relationship between biodiversity and ecosystems requires an understanding of the characteristic of species, their function within an ecosystem, and how they interact.

It is likely to be several decades before scientists can confidently say they have a good grasp of all these issues. But we already know enough to be able to predict that biodiversity-poor landscapes will recover more slowly from floods, droughts or fire; and that they will be less able than biodiversity-rich ones to resist invading species or the spread of emerging diseases.

We also know, on the basis of both observation and scientific research, that what are called ecosystem services – such as pollination, the production of clean water, and productive fisheries and forests – become less effective as biodiversity decreases. The challenge to policymakers is to design effective measures to prevent this from happening.

Further reading

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