THE WORLD'S SPECIES ARE PLAYING MUSICAL CHAIRS

Many communities aren't losing biodiversity, but ecosystems are changing rapidly and the future is far from rosy. **By Gayathri Vaidyanathan**

MATTHEW LOVETTE/EDUCATION IMAGES/UIG/GETTY

The number of plant species in New Zealand has doubled since humans settled there about 800 years ago.

In June 2018, 180 cars fanned out across Denmark and parts of Germany on a grand insect hunt. Armed with white, funnel-shaped nets mounted on their car roofs, enthusiastic citizen naturalists roamed through cities, farmlands, grasslands, wetlands and forests. The drivers sent the haul from their 'InsectMobiles' to scientists at the National History Museum of Denmark in Copenhagen and the German Centre for Integrative Biodiversity Research in Leipzig.

The researchers dried and weighed the collections to determine the total mass of flying insects in each landscape. They expected some bad news. The previous year, scientists in Germany had found that the flying-insect biomass in their nature reserves had plunged by 76% over 27 years[1]. Similar studies had led to news headlines that screamed of an ongoing "insectageddon" and "insect apocalypse". British columnist George Monbiot wrote in *The Guardian*: "Insectageddon: farming is more catastrophic than climate breakdown".

But when the researchers tallied the InsectMobile results[2], they didn't see evidence of declines everywhere. Insect biomass totals were higher than expected in agricultural fields, and indeed in all places except cities in their study, which is yet to be peer reviewed[2]. Aletta Bonn, an entomologist at the Leipzig centre and a co-author of the study, says this could be because the fertilizers that farmers use are leading to lush plant life, which is reverberating through the ecosystem. That said, she cautions, not every insect species in the study area might be doing well; some could be thriving, others not so much.

"We do need to understand better what kind of insects are affected and to which degree," Bonn says. "I think the generalization that all agriculture is bad — I wouldn't say so."

The findings resonate with what biologist Mark Vellend and his colleagues have seen in their studies of trees at the edge of boreal forests in eastern Canada. They've found that spruce, eastern white cedar, eastern hemlock and American beech have been struggling to

maintain their roothold since European and American settlers began clearing land more than a century ago. But poplar, paper birch, maple and balsam fir are thriving[3]. Vellend, who teaches at the University of Sherbrooke in Quebec, Canada, poses a question to his students every year: if they were to count the plant species in the province, would the number have gone up or down since Europeans arrived?

Most students so far have got it wrong. "Many of them are surprised to learn that there's 25% more [species] than there were 500 years ago, before people of European origin laid a foot here," Vellend says.

Something odd is going on in biodiversity studies. Scientists have long warned that animal and plant species are disappearing at an alarming rate. In 2019, an international group of hundreds of researchers produced the most comprehensive report on biodiversity ever assembled, and they concluded that some one million animals and plant species are facing extinction. On top of that, humans have cleared landscapes and chopped down nearly one-third of the world's forests since the Industrial Revolution — all of which bodes poorly for protecting species.

So, scientists naturally assumed that they would find precipitous declines in biodiversity nearly everywhere they looked. But they haven't. And a consensus is emerging that, even though species are disappearing globally at alarming rates, scientists cannot always detect the declines at the local level. Some species, populations and ecosystems are indeed crashing, but others are ebbing more slowly, holding steady or even thriving. This is not necessarily good news. In most places, new species are moving in when older ones leave or blink out, changing the character of the communities. And that has important implications, because biodiversity at the small scale has outsize importance; it provides food, fresh water, fuel, pollination and many ecosystem services that humans and other organisms depend on.

"Ecosystems don't work at the global scale," says Maria Dornelas, an ecologist at the University of St Andrews, UK. "I'm interested in what is happening to biodiversity at the local scale, because that's the scale that we experience."

Scientists say it's clear that there's a biodiversity crisis, but there are many questions about the details. Which species will lose? Will new communities be healthy and desirable? Will the rapidly changing ecosystems be able to deal with climate change? And where should conservation actions be targeted?

To find answers, scientists need better data from field sites around the world, collected at regular intervals over long periods of time. Such data don't exist for much of the world, but scientists are trying to fill the gaps in Europe. They are planning a comprehensive network, called EuropaBON, that will combine research plots, citizen scientists, satellite sensors, models and other methods to generate a continuous stream of biodiversity data for the continent. The effort will inform European policymakers, who are pushing for a strong and verifiable global biodiversity agreement when nations next meet to renew the United Nations' Convention on Biological Diversity (CBD) — an international pact to halt and reverse biodiversity loss.

How to measure biodiversity

Biological diversity is a shape-shifting term that has been used in many ways. The CBD takes a broad approach, defining it as "the variability among living organisms from all sources". This includes, it says, "diversity within species, between species and of ecosystems".

"Everybody could sign up to such a definition," says Chris Thomas, an ecologist at the University of York, UK. "It means that different people can pick on different aspects that are all included within that all-encompassing definition, and find almost whatever trend they want."

Scientists measure biodiversity through many metrics, but the most common is species richness: a simple count of the number of species in the area. They also check the relative abundance of different organisms — a metric called species evenness — and track the identity of species to learn the 'community composition'. Further complicating matters, scientists sometimes tally biomass instead of species richness, especially when it comes to insects.

> **"I've now learned not to assume I know what's going on until I've seen what the data show."**

Using such measures, the clearest signal that the world is losing biodiversity comes from the bookkeeper of species, the International Union for Conservation of Nature. It has found that 26% of all mammals, 14% of birds and 41% of amphibians are currently threatened globally. Insufficient data are available for other groups, such as most plants and fungi. Extinction rates in the past few centuries are much higher than they had been before humans started to transform the planet; some estimates suggest current rates are 1,000 times the background level. One calculation estimates that, if high rates continue, then within 14,000 years, we could enter the sixth mass extinction — an event similar to the one that wiped out about three-quarters of the planet's species, including dinosaurs, 65 million years ago[4]. For the most critically endangered species, the death knell could come within decades.

More bad news comes from the United Nations-backed Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) — the organization behind the 2019 report warning that about one million species were threatened by extinction. The report also found that the abundance of native species in local terrestrial ecosystems has dropped by an average of around 20% as a result of human activities.

Another biodiversity report that draws considerable attention comes from the conservation organization WWF and the Zoological Society of London, among other groups. Every year, they produce the Living Planet Index, which has amassed data for 27,695 populations of 4,806 vertebrate species. Last year, the report stated that population sizes of birds, mammals, fish, amphibians and reptiles declined, on average, by 68% between 1970 and 2016.

Some researchers worry that such averaged figures can hide a lot of nuance, because many people might assume incorrectly that the average applies to most species. Dornelas likes to illustrate the danger by pointing out that the 'average human' has one breast and one testicle, and doesn't exist.

Last year, Brian Leung, a biologist at McGill University in Montreal, and his colleagues re-analysed the Living Planet Index data from 2018 and found that a handful of populations are declining catastrophically, strongly pulling down the average. If these outliers are dropped from the computation, 98.6% of the populations on the index are holding steady or increasing or declining more slowly[5]. "We're not saying there are not problems," says Leung, who stresses that declines are still bad. "But there should be some caution about using these really broad-based global metrics, even though they are pretty powerful statements. But they can mask a whole lot of variation and be driven by extreme outliers."

When scientists talk about the world entering a sixth mass extinction, what sometimes gets lost is the timescale. Extinction rates for past periods of Earth's history are calculated per one million years, and at present, researchers are seeing vertebrate species disappear at a rate of about 1% every century, and most of that has happened on islands.

It's clear there is a biodiversity crisis right now, although the pace is uncertain, says Henrique Pereira, a conservation biologist at the German Centre for Integrative Biodiversity Research , and a co-chair of an IPBES expert group. "It doesn't mean that there is no decline. It means that if there is a decline, it's much smaller than what maybe we thought."

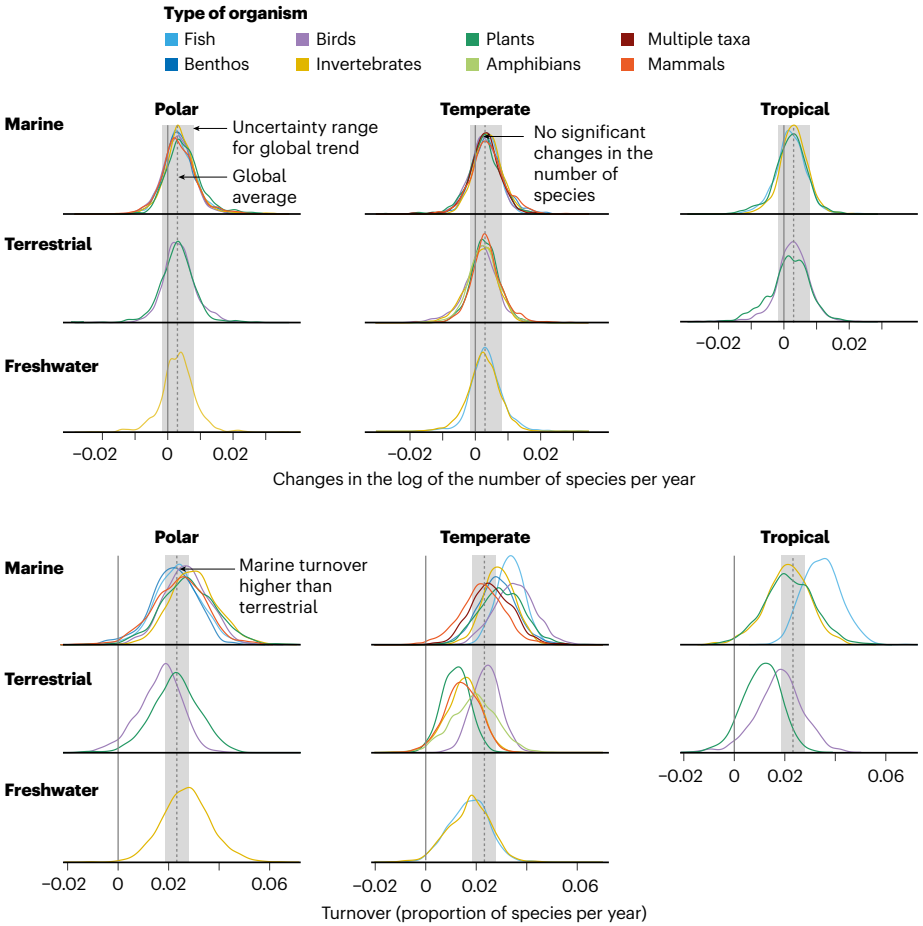
So is the sixth mass extinction happening? "Well, not yet, if you want my scientific assessment of it. But is it going to be starting? Yes, maybe starting," says Pereira.

Difficult message

In 2012, Vellend and his colleagues decided to see what's happening with plant biodiversity by looking at a collection of individual field sites around the world. They compiled

LIFE ON THE GO

A meta-analysis of 239 biodiversity studies found that, at the local level, there was not much change in species richness — the number of organisms in a community — over the span of each study. But there was considerable turnover in most groups and locations, as some species left and others moved in.



more than 16,000 studies in which scientists had monitored plants for at least 5 years, and found that only 8% of the studies noted a strong decline in the total number of species. Most plots showed either no change, smaller declines or even an increase in biodiversity[6].

The study was rejected by *Nature*, and one reviewer worried that journalists would garble the results and give the false impression that there were no problems with biodiversity. A *Nature* spokesperson says the peer-review process is confidential and that editorial decisions are not driven by considerations of potential media coverage. (*Nature*'s news team is editorially independent of its journal team.)

Vellend eventually published the study in the *Proceedings of the National Academy of Sciences* in 2013 (ref. 6).

His conclusions were soon backed up by Dornelas and her colleague Anne Magurran, an ecologist at the University of St Andrews, who have been compiling a database of biodiversity field studies, called BioTIME, since 2010. The database now has more than 12 million records for about 50,000 species from 600,000 locations around the world.

In a study of 100 field sites worldwide, Dornelas and her colleagues had expected to find declines in species richness and abundance, but the data showed otherwise. Many sites were declining in biodiversity, but an equal proportion were improving. And about 20% showed no change over time. Overall, there wasn't a clear trend[7].

At first, the researchers didn't believe the results, so they reanalysed the data several ways and finally published the findings in 2014.

"It was this tremendous shock. What's going on?" says Pereira, who wasn't involved in the study.

Dornelas says reactions were mixed. Some people worried that the results could be misconstrued to suggest that everything's fine with biodiversity. Others went even further. "Some people questioned our integrity, which is something that I take offence at, because being an ethical scientist is at the core of what I do," she says. "But other people reached out to us and said, 'Oh, interesting, that sort of matches my experience.'"

Since then, many studies looking at biodiversity in the oceans, rivers, among insects — almost any grouping or biome one can think of — have found that there is no clear trend of decline. But that doesn't mean the ecosystems are remaining static. Dornelas and her colleagues have continued to mine the BioTime database and have found that the mix of species in local communities is changing rapidly almost everywhere on Earth[8] (see 'Life on the go'). As some inhabitants disappear, colonizers move in and add to species richness, so the 'average ecosystem' shows no change or even an increase in the number of species, she says, with her usual cautions about averages[9].

"Species are at the moment playing musical chairs," says Dornelas.

This can be seen most clearly on isolated islands, where 95% of the world's extinctions have happened. Take New Zealand, where there were no mammalian predators before humans first settled there, less than 800 years ago. Since then, nearly half of New Zealand's endemic birds have gone extinct.

But despite the extinctions, biodiversity, measured by species richness, has improved over time in New Zealand, Vellend says. Continental birds have replaced the lost endemics. Plant biodiversity is doing well; fewer than 10 native species have gone extinct, and there are now 4,000 plant species on the islands, up from 2,000 before human settlers. And there are more than two dozen new land mammals.

The lesson is that species richness or abundance figures might not tell the whole story, says Dornelas. Rather, scientists need to know the identity of all the species in a community, and track their relative abundances. This will allow them to learn which species are declining and which could be targeted for conservation.

The story is similar on the continents, except with fewer complete extinctions. In Denmark over the past 140 years, 50 plant species have declined in abundance and range, but 236 have expanded their habitats. The large majority are holding steady[10]. Scientists looking at Europe's birds since 1980 have found that 175 species are declining while 203 are increasing[11]. Rare birds are doing better than more common species, such as the house sparrow (*Passer domesticus*). A study of vertebrates in North America and Europe by Leung and his colleagues found that, whereas amphibians are declining across the board, other taxa have winners and losers in roughly equal measure[12].

Even corals seems to show the same pattern: between 1981 and 2013, 26 genera in the Caribbean and Indo-Pacific became more abundant, while 31 declined[13].

With studies piling up, it's become increasingly acceptable for scientists to say that biodiversity isn't declining everywhere and for all taxa, says Dan Greenberg, an ecologist at University of California, San Diego. "The tide is turning," he says, "but the field is grappling with how to translate that to a public audience, or what does that mean in terms of social consequences."

That doesn't mean there's no biodiversity crisis, stresses Helmut Hillebrand, an ecologist at the University of Oldenburg in Germany.

SOURCE: REF. 8

Some scientists worry that unusually high turnover, together with signals of instability in some populations, could itself portend ecological collapse. Humans are carrying species into new environs, leading to colonization. Whereas climate change is spurring warm-loving species to expand into new zones, cold-adapted species are losing out. Plus, generalist species that are fast-growing and less particular about where they live are thriving in human-modified landscapes.

Specialists that need highly specific environments or that disperse poorly get easily isolated, which increases their extinction risk, says Greenberg. Case in point: amphibians. "If something changes in that environment, you can't really hop over to another site very easily," he says.

Turnover could lead to distant communities that increasingly resemble each other — a process called homogenization that has been documented in particular regions and taxa. In 2015, César Capinha, a biogeographer at the University of Lisbon, and his colleagues found that snail populations in temperate regions as far flung as Virginia, New Zealand and South Africa had species in common, thanks to human travel and trade[14]. Similarly, in the plant study in Denmark, scientists found that plant communities are increasingly looking like each other and are dominated by generalists. Scientists worry that such landscapes might not be resilient to environmental change.

Dornelas urges caution in interpreting the changes seen so far. There hasn't yet been a robust global study of homogenization to know the extent to which this is happening. And there is also increased habitat fragmentation, which can counter this process. "We don't often talk about both of those at the same time," Dornelas says. "I've now learned not to assume I know what's going on until I've seen what the data show."

Scientists have also observed cases in which a colonizer mixes with a resident to rapidly form a new hybrid species, especially in plants, says Thomas. But it's unclear how long these hybrids will persist, and most other groups usually take one million years or so to form new species. Many of the beasts of today could go extinct before that process can catch up, says Dolph Schluter, an evolutionary biologist at the University of British Columbia in Vancouver, Canada. "We are going to lose a lot of the ancients. And no amount of evolution in the short term is going to replace those," Schluter says.

Keeping tabs on life

Global studies of biodiversity have important biases owing to data gaps. Most of the records of species come from Europe and North America; there are very few data from the tropics, where rainforests house half of all species in just 7% of the Earth's surface. And even in the most richly monitored places on Earth, such as Europe, the data are patchy. "We are trying to read the book, but we have only a few letters," says Pereira.

ALEXIS ROSENFELD/GETTY

Lionfish have invaded the Red Sea, one example of species changes seen in many places.

Pereira and his colleagues are designing a top-down monitoring network in Europe called EuropaBON that can add in more letters, and maybe even sentences. The project has received €3 million (US$3.5 million) from the European Commission, and was launched last December. Pereira and Jessica Junker, the scientific coordinator of EuropaBON and a conservationist at Martin Luther University Halle-Wittenberg in Germany, have assembled a 350-strong community of national conservation authorities, non-governmental organizations, scientists and government officials. Among the first goals is to create a map that identifies data gaps as well as a list of metrics to be tracked, Pereira says. At the end of the initial three-year stage, EuropaBON aims to set up a coordinating centre for the monitoring network.

It'd have to be affordable to be replicable and maintained over time. Lack of funds has hampered a global version of this project, called GEO BON, on which EuropaBON is based, says Dornelas. To contain costs, EuropaBON intends to use existing long-term monitoring sites. Where there are data gaps, the scientists would launch new tracking efforts using technology such as sensors, weather radar and drones, or citizen volunteers, who already do 80% of the biodiversity monitoring in Europe.

EuropaBON would also use satellite data of land cover, vegetation growth and other indicators of local biodiversity. The data streams would be combined with modelling to generate seamless biodiversity data over time and across Europe. The plan is that data from the project will help the European Commission to decide what research to fund on the continent's biodiversity, says Pereira. In a stakeholder meeting in May for EuropaBON, Humberto Delgado Rosa, the director for natural capital at the European Commission, said that the European Union wants to make "huge leaps internationally in biodiversity, as it has done with climate in Paris". EuropaBON should help Europe to meet its international commitments to report on its biodiversity, Rosa said.

"This new global biodiversity framework needs quantification, measurability," he said. "In a nutshell, we need knowledge."

Dornelas, who is also part of EuropaBON, says she would like to expand this initiative across the world. Canada is exploring a national version, called CanBON. But for now, monitoring remains sparse in the poorer parts of the world, where most of the planet's biodiversity remains.

"Europe is one of the best monitored parts of the planet, and where we're really, really missing data is from other parts of the world," she says. "But I guess we got to start somewhere."

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