The biodiversity revolution

Ecologists are increasingly looking at traits — rather than species — to measure the health of ecosystems.

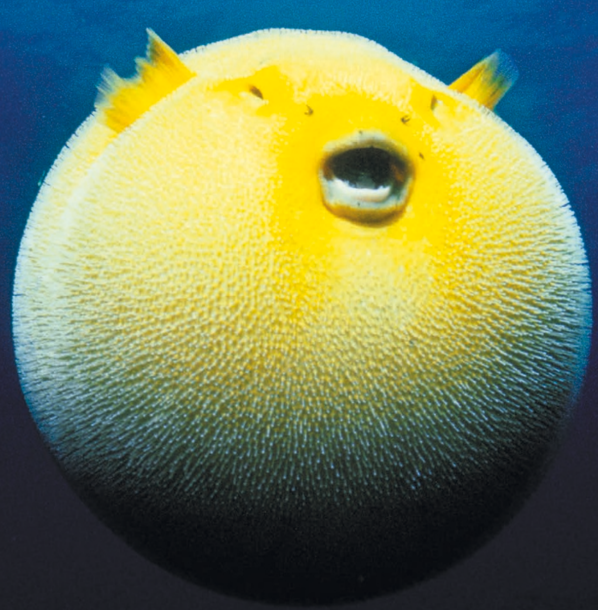
BY RACHEL CERNANSKY

Emmett Duffy was about 5 metres under water off the coast of Panama, when a giant, tan-and-white porcupinefish caught his eye. The slow-moving creature would have been a prime target for predators if not for the large, treelike branches of elkhorn coral (*Acropora palmata*) it was sheltering under. The sighting was a light-bulb moment for Duffy, a marine biologist. He'd been to places in the Caribbean where corals were more abundant and more diverse, but smaller; the fish there were always small, too. Here, in the Bocas Del Toro archipelago, he was seeing a variety of big fish among the elkhorns. "The reason these large fish were able to thrive," he says, "was that there were places for them to hide and places for them to live."

For Duffy, that encounter with the porcupinefish (*Diodon hystrix*) brought to life a concept that had long been simmering in the back of his head: that the health of an ecosystem may depend not only on the number of species present, but also on the diversity of their traits. This idea, which goes by the name of functional-trait ecology, had been part of his lab work for years but had always felt academic and abstract, says Duffy, now director of the Smithsonian Institution's Tennenbaum Marine Observatories Network in Washington DC.

It's an idea that's increasingly in vogue for ecologists. Biodiversity, it states, doesn't have to be just about the number of a species in an ecosystem. Equally important to keeping an ecosystem healthy and resilient are the species' different characteristics and the things they can do — measured in terms of specific traits such as body size or branch length.

That shift in thinking could have big implications for ecology. It may be necessary for understanding and forecasting how plants and animals cope with a changing climate. And functional diversity has started to influence how ecologists



Common species such as this guineafowl pufferfish (*Arothron meleagris*) may have important functions in their ecosystems.

think about conservation; some governments have even started to incorporate traits into their management policies. Belize, for example, moved several years ago to protect parrotfish species from overfishing — not necessarily because their numbers are dwindling, but because the fish clean algae from coral and are crucial to reef survival.

"Just going for species numbers basically doesn't allow us to harness all this incredibly rich information we have of how the real world operates," says Sandra Díaz, an ecologist with Argentina's National Scientific and Technical Research Council (CONICET) and the University of Córdoba. Still, some experts are concerned. How traits are defined remains a source of debate, and without robust data on trait and species diversity in settings around the world, any choices directed by the approach could turn out to be short-sighted. "I'm really excited, but I worry," says Walter Jetz, an ecologist and evolutionary biologist at Yale University in New Haven, Connecticut. "We as a community need to be really careful in appreciating the data limitations that exist."

QUALITY VERSUS QUANTITY

For decades, the study of biodiversity was essentially a numbers game: the more species an ecosystem had, the more stable and resilient to change it was thought to be. That mindset made sense because there was so little information available about the structures of an ecosystem and the functions of species within it. The technology didn't exist to measure many traits or to process the large amount of data that would have resulted if they could have been measured. Various developments have changed that. Advances in molecular biology have enabled the study of microbes en masse. Satellites can assess traits such as tree-canopy height and marine plankton productivity. And leaps in statistical tools and computing power have helped to make use of all the data that are now being generated.

Some trace the new way of thinking about ecosystems — at least in formal research — to ecologist David Tilman at the University of Minnesota in St Paul. In 1994, he published a landmark paper[1] that tracked species diversity in Minnesota grasslands through a major drought in the 1980s. Species-rich areas tended to weather the drought much better than those with few species, supporting the link between diversity and stability. But the relationship wasn't linear. Only a few drought-resistant grasses were needed to greatly enhance a plot's ability to rebound.

Three years later, Tilman and his collaborators published findings[2] from 289 grassland plots they had planted with varying numbers of species and levels of functional diversity. Here, the presence of certain traits, such as the C_4 photosynthesis pathway or nitrogen fixation, made a bigger difference to the plots' overall health than the number of species.

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Around the same time, Shahid Naeem, director of Columbia University's Earth Institute Center for Environmental Sustainability in New York City, was also looking beyond species numbers to study ecosystem function, zeroing in on the diversity of species at different levels of the food web. Looking at species number alone, he says, is like listing the parts of a car without saying what they do. That provides no guidance for when things start to break down, he says. "We just sort of stand there scratching our heads like primitive people who've never seen a car before, saying, 'The car's not working now, I wonder what's wrong with it.'"

From the mid-1990s, studies of functional diversity started to take root. Work on plants and forests led the charge because it is relatively easy to manipulate such systems. But the approach gradually expanded to include birds, sea life and soils. Diana Wall, a soil ecologist at Colorado State University in Fort Collins, says that she and her colleagues have focused on functional traits and diversity for years, in part because the activities of soil microorganisms are often easier to identify than the species themselves. She is excited that researchers are developing a firmer grasp of traits and species above and below ground. "New knowledge on both fronts brings us understanding of the dependence on species and functions," she says.

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GET YOUR PRIORITIES STRAIGHT

Conservation biologists are excited about functional traits because they could influence decisions about what to protect. Researchers and environmentalists have typically focused on regions brimming with species, such as the Amazon rainforest and Australia's Great Barrier Reef. But Rick Stuart-Smith, an ecologist at the University of Tasmania in Taroona, Australia, has suggested reframing the definition of a biodiversity hotspot. Integrating functional traits could point to the importance of previously understudied areas. For Stuart-Smith, it's too early to identify specific places that would qualify — more in-depth research is needed. But, he says, functional-trait ecology should ultimately extend to conservation strategies and how governments choose which areas to protect.

And the new way of thinking about diversity could reveal vulnerabilities that weren't recognized before. Species-rich areas may seem to have a sort of insurance against loss of traits because the functions the traits provide are assumed to be found in many species, says David Mouillot, a marine ecologist at the University of Montpellier in France. But some functions are provided by only one species, or a few. He and his colleagues are racing to locate these rare functions.

The lens of functional diversity helps to create a more nuanced picture of ecosystems. Greg Asner, an ecologist with the Carnegie Institution for Science's Department of Global Ecology at Stanford University in California, has used a unique spectral imager to map 15 traits for forests across Peru. Conventional studies recognized three types of forest in the country using the species-richness concept, says Asner — dryland, floodplain and swamp forest. But Asner and his team looked at which traits could help to distinguish new functional groups, and found that seven were key. They then classified the forests based on those traits, and came up with 36 classes representing different combinations of the seven traits[3]. The researchers used their findings to help Peru rebalance its conservation portfolio.

Asner says he's also been asked to identify a 400,000-hectare area in northern Borneo to set aside for protection on the basis of traits. "They want to know, where is the million acres where you can get the most variation in traits?" he says. "Where can you put a fence around the most functional variation?"

That level of interest is encouraging to him and other researchers because ecosystems are so complex that once certain species, functions or ecosystem processes are lost, there's no getting them back — at least not using current techniques or knowledge. "We don't have the science or technology on Earth to engineer a forest from scratch the way that nature and evolution have," says Asner.

Some experts, however, advise against making decisions based on functional traits until more complete data are available. "As soon as you're missing a single species in your data matrix, you may be missing a key function that is only represented by that species," says Jetz, who has studied functional traits in plants and vertebrate animals, particularly birds. He warns not only about gaps in data, but also about biases — such as where researchers choose to sample, which can skew a data set towards or away from certain regions or types of environment.

Naeem, too, would like to see a concerted global effort to create a more complete and comprehensive database of traits for the natural world. "When we get really excited about

DAVID DOUBILET/NGC/ALAMY

The branches of elkhorn coral (*Acropora palmata*) provide shelter for large fish, but researchers disagree on whether this is a functional trait or an interaction.

a field, one of the big, major investments and efforts that everybody has to get behind is getting the data that we need," he says.

Some work is afoot to build such databases for both terrestrial and aquatic environments. TRY, hosted at the Max Planck Institute for Biogeochemistry in Jena, Germany, is an international network of plant scientists who have been building a publicly accessible database of traits and functions since 2007. It now contains records for 100,000 plant species.

There's also the ReeFish database, now led by Mouillot, which aims to provide trait and geographic information for all tropical reef fish. And the Reef Life Survey, begun in Tasmania by Stuart-Smith and marine ecologist Graham Edgar in 2007, has trait records for more than 5,000 species from all ocean basins.

Duffy, meanwhile, is spearheading the Smithsonian's Marine Global Earth Observatory programme, which he says is a "major opportunity to map out the links between diversity and functioning of marine ecosystems on a global scale". There are currently ten sites in the network, which aims to establish a global, pole-to-pole presence.

These are all works in progress, and despite wide agreement on the importance of focusing on functional traits across ecosystems, there doesn't yet seem to be a clear definition of what a trait is. Agreeing on one that spans the plant and animal kingdoms will be difficult. How detailed should one get? Is it appropriate to stop at observable traits, such as leaf size, or to dig into individual gene sequences?

Diet seems to be a grey area. Some researchers include dietary patterns when they evaluate an organism's functional traits, for example, by looking at whether it can eat a variety of organisms or is specialized to feed on a single flower species. Others scoff at including diet. "If it's not on a genome, it's not a trait," says Naeem, who points out that foxes may have certain dietary preferences, but will still eat packaged dog food, given the chance. He says that traits linked to genes — tooth size in a predator, for example — will influence diet and can be used to infer feeding patterns.

TRAIT TALKING

Interactions between species open up another area of debate. Some might interpret a porcupinefish taking shelter among corals, as Duffy observed in Panama, as an interaction between species — and not count it as a trait. For Duffy, however, traits can influence, and be a reflection of, how species interact with each other. The traits of the coral — its branch structure and size — are what enabled the fish to thrive.

Whether or not to rank the importance of traits to an ecosystem is another area of contention. Some researchers are working to identify the most valuable traits, whereas others, such as Mouillot, take a more agnostic approach. "We do not rank them. We do not say two or three traits are the most important and the other ones are marginal," he says.

And for all the focus on functional diversity, it is probably just one step towards finding a truly comprehensive view of biodiversity — the ultimate goal for ecologists and conservationists. Simultaneous work is being done on the evolutionary histories of species in an ecosystem in an attempt to understand and mitigate the effects of biodiversity loss. Some view this 'phylogenetic diversity' as the third leg of the stool with functional and species diversity. And researchers around the world are working to fill in other gaps, too. A large German consortium has been studying how land-use intensification affects functional diversity, and more work needs to be done on the role of spatial data and interactions at the landscape level, rather than in microcosms or individual study sites.

For now, however, researchers are embracing functional traits for the sophistication they have already added to understanding of ecosystems. That includes Jetz — despite his warnings against making decisions based on functional diversity too soon. The data may be incomplete, but functional traits could potentially convey the importance of ecosystems to people outside the scientific community, including policymakers and economists, in a more tangible way than species richness ever has. "If you lose a species or two, it's hard to interpret what that means," Jetz says. But being able to show explicitly how the loss of a function could decimate an ecosystem might have a bigger impact. "It's something that more people are able to relate to." ■ SEE EDITORIAL P.7

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1. Tilman, D. & Downing, J. A. *Nature* **367,** 363–365 (1994).
2. Tilman, D. *et al. Science* **277,** 1300–1302 (1997).
3. Asner, G. P. *et al. Science* **355,** 385–389 (2017).