Tackling the great paradox of biodiversity with game theory

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One of the main puzzles of ecology research has been to explain how hundreds, often thousands, of species coexist in environments with a very limited number of resources. Scientists in Lisbon, Portugal, have a promising answer to this conundrum, which could resolve a longstanding paradox and have important implications for preserving biodiversity, one of the more pressing challenges of our time.

For decades, scientists struggled to explain how scarce resources can sustain the multitude of species that exists on Earth. Early theoretical attempts to understand biodiversity led to a nonsensical situation. Theory predicted that the number of species had to be equal to the number of resource types available in the environment, a conclusion that clearly fails the test of reality. The contrast between the theoretical prediction and the experimental observation is so glaring that it has been called paradoxical.

This paradox is often known as the "plankton paradox," because it is very crisply illustrated by the properties of plankton ecosystems. In open sea water, there are fewer than 10 growth-sustaining resources such as light, nitrogen, carbon, phosphorus, iron, etc. Yet even there, hundreds of species of plankton are able to stably coexist without driving each other extinct.

Despite recent progress, this enigma of biodiversity has not yet been solved. Now, scientists at the Champalimaud Centre for the Unknown, in Lisbon, Portugal, developed a new mathematical model which may be the answer. Their findings were published in the scientific journal *Proceedings of the Royal Society B*.

According to Andres Laan, the first author of the study, led by principal investigator Gonzalo de Polavieja, classical resource competition models predict that each resource will sustain the one species that is best at consuming it, consequently driving all competing species to extinction. But this one-to-one correspondence is not what we observe in nature. On the contrary, the number of species living on Earth is orders of magnitude larger.

The scientists set out to provide a new solution to the plankton paradox. The novelty of this study is that, to explain the biodiversity paradox, they used game theory models of aggression as their source of inspiration. "We started from a theoretical scenario where we had just two 'species': hawks and doves," Laan explains. "Hawks are bloodthirsty and always ready to fight. Doves are pacific and tend to split resources or run away from fights. According to game theory, in the end, neither purely hawks nor purely doves are dominant, but instead the two 'species' coexist."

They wondered what would happen if various species played this hawk-dove game over many types of resources simultaneously. For each resource, a species had an independent choice between being a hawk or being a dove. "This rich set of choices generated combinatorial diversity, leading to a large number of potential species, and just as was the case for the simple hawk-dove game, the species ended up coexisting, rather than driving each other extinct," says Laan.

According to their model, biodiversity actually increases exponentially with the number of resources. "On one resource, two species can coexist, on two resources, four species, on four resources, 16 species, and on 10 resources, we get to more than 1000 species. Exponential growth is very fast, so it provides a nice way to maintain biodiversity," he explains.

Their theory, the authors say, also has a number of experimentally confirmed predictions. The model precisely captures how abundant species are in real ecosystems. In these ecosystems, there are a few species that are most abundant, yet they account for a disproportionately large fraction of the total biomass in the system. "You can think of this as being similar to wealth inequality in human societies, where the rich hold a disproportionately large share of total wealth," says Laan.

The authors believe that resolving this paradox might provide the key not only to understanding biodiversity, but also understanding extinctions and predicting possible future directions of animal evolution. "These ideas are still largely theoretical, so we need to test how well the competition mechanisms proposed in the paper describe what happens when real species compete, but early results look quite promising," Laan concludes.

More information: Species diversity rises exponentially with the number of available resources in a multi-trait competition model, *Proceedings of the Royal Society B*, rspb.royalsocietypublishing.or … .1098/rspb.2018.1273

Provided by Champalimaud Centre for the Unknown

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