Researchers introduce new model that bridges rules of life at the individual scale and the ecosystem level

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Christopher Klausmeier, a Michigan State University Research Foundation Professor, and Elena Litchman, a senior staff scientist with the Carnegie Institution for Science, study plankton, in part, to better understand the fundamental rules of nature. Credit: Bethany Bohlen/W. K. Kellogg Biological Station/MSU

Researchers at Michigan State University and the Carnegie Institution for Science have developed a model that connects microscopic biology to macroscopic ecology, which could deepen our understanding of nature's laws and create new opportunities in ecosystem management.

Reporting in the journal Science the team showed how microscopic relationships in plankton—such as between an organism's size and nutrient consumption—scales up to predictably affect food webs.

"Using data that other researchers have measured at the microscale about these organisms, our model can predict what's happening at the scale of whole ecosystems," said Jonas Wickman, a postdoctoral research associate with MSU's College of Natural Science and first author of the new paper.

"We can now show how lower-level rules of life feed into these higher levels based on ecological interactions and evolutionary considerations," said Elena Litchman, a senior staff scientist at Carnegie's Biosphere Sciences and Engineering division. "Up until now, people had mostly considered these levels in isolation."

This new report will enable the team and its peers to design new experiments to test, refine and expand the model by extending it to other species and ecosystems. This could ultimately lead to the model being able to inform ecosystem management strategies in various environments around the globe.

Small organisms, global impact

The team is also interested in what more they can learn from their model and the plankton they study.

"We chose them as a model system for a few reasons," said Christopher

Klausmeier, an MSU Research Foundation Professor at the W. K. Kellogg Biological Station. He's also a faculty member with the Department of Plant Biology, the Department of Integrative Biology and the Ecology, Evolution and Behavior, or EEB, program at MSU.

One of the reasons is that plankton are the primary research focus for the research group led by Litchman and Klausmeier.

"They're relatively simple organisms. If anything is going to follow the rules, plankton are a good candidate," Klausmeier said. "But they're also globally important. They're responsible for about half of the primary production on Earth and are the base of most aquatic food webs."

Primary producers use biochemical processes such as photosynthesis to turn the Earth's carbon and raw nutrients into compounds that are useful for the organisms themselves and their predators. This means plankton are a critical cog in the natural machinery that cycles the planet's life-essential elements, including carbon, nitrogen and oxygen.

Having this scaling model that describes plankton can thus be useful for better understanding those key processes, as well as if and how those are changing with the planet's climate.

The team did not include climate-associated variables like temperature in this study, but the researchers are already planning their next steps in that direction.

"The effects of global warming could alter the lower-level physiological processes," Litchman said. "We could then use this framework to see how those effects bubble up to different levels of organization."

Eye-popping simplicity

Wickman hasn't always been a plankton ecologist. His undergraduate degree was in physics, but he switched to ecology during his doctoral studies in Sweden before joining the Klausmeier-Litchman lab in 2020.

The team said his physics background shaped his approach to developing this model, which Litchman described as "beautiful—stripping out everything except the essential processes."

To begin, Wickman built from fundamental theories describing his system of interest. Only in this case, the system wasn't, say, quantum mechanical particles. It was tiny organisms linked by a simple food web.

Within that web, phytoplankton are the primary producers and zooplankton are their predators.

"Well, grazers really," Wickman said of the zooplankton. "We don't usually call cows predators of grass."

To fully appreciate the workings of this important relationship and its global implications, researchers have been breaking it down into its components driven by ecology and evolution.

For example, microscopic considerations like the size of a phytoplankton affect its ability to compete for nutrients, which in turn influence how big cells can get and how likely it is to become food for zooplankton.

These microscopic factors are thus connected to macroscopic variables, including the distribution of nutrients and how densely or sparsely different plankton populate their environments.

Over the past several decades, scientists have formulated mathematics that describe important relationships at the micro scale and macro scale individually. Attempts to bridge the scales, however, have left researchers wanting, Wickman said.

That's because previous attempts to make that connection have had to make compromises. Some previous models have chosen simplicity at the expense of accuracy and realism. Others have confronted that complexity with brute computational force, making them less accessible and harder to work with.

"Our model includes actual ecological and evolutionary mechanisms but is simple enough to use," Wickman said.

The work began as pure theory, but Litchman suggested that it should be possible to test its predictions using existing data. "When I saw how well the model matched the observations, my eyes popped out," she said.

The team had been working on this problem for several years and had published an earlier paper developing the eco-evolutionary modeling techniques they relied on.

Now, the team has showcased the potential of their model by uniting it with real-world data.

"The revelation that patterns emerging at macroecological scales can be explained by properties of individual organisms at microecological scales is as compelling as it is elegant," said Steve Dudgeon, program director in NSF's Directorate for Biological Sciences, which helped fund the work.

"The study provides new avenues of research that could enhance prediction of how ecosystems, and the relationships among the organisms in them, will change with eco-evolutionary dynamics interacting in changing environments."

Because of the natural variation of biological systems, the model and its results may seem messy to someone used to the precision of physics, but Wickman views them with excitement.

"We actually achieved quite good accuracy for ecology," he said. "We may not have the same level of theoretical elegance as physics, but that just means we have much more territory to explore."

More information: Jonas Wickman et al, Eco-evolutionary emergence of macroecological scaling in plankton communities, *Science* (2024). DOI: 10.1126/science.adk6901. www.science.org/doi/10.1126/science.adk6901

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