Illuminating interactions between decision-making and the environment

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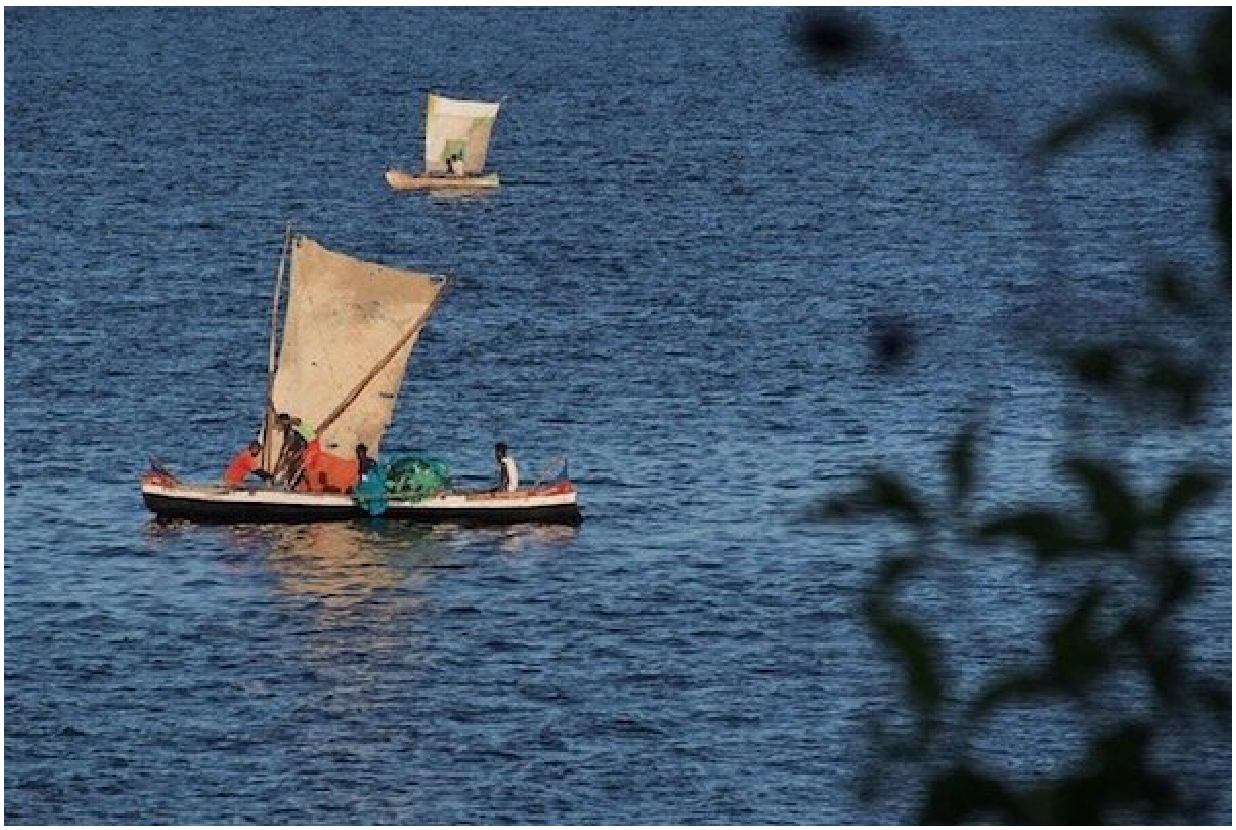

Aunifying game theory model describing the feedbacks that occur between strategic decision making and environmental change captured dynamics that occur in fisheries, in human social interactions, in soil-microbe interactions, and much more. Credit: Erol Akçay

In a heavily polluted environment, does it make more sense for a company to keep polluting or start cleaning up its act? If it chooses to employ cleaner technologies and the environment becomes healthier, does the same calculus apply?

These feedbacks between decision strategy and the environment come up in fields as diverse as fisheries, economics, and human social interactions. Game theorists have explored these so-called feedbacks using individual models to apply to particular scenarios. But in a new publication in *Nature Communications*, researchers from Penn's School of Arts and Sciences present a unifying model that explains these diverse interactions and underscores the similarity of their features.

"What we do in our paper is try to explicitly incorporate the way in which evolutionary game dynamics can be affected by the environment and can change the environment," says Andrew Tilman, first author on the paper and a postdoctoral researcher in the Department of Biology. "So, you get this feedback between strategies that are used in the game and environmental change."

Tilman coauthored the work with advisers Erol Akçay and Joshua Plotkin, faculty members whose work specializes in theoretical and computational approaches to biological questions.

The findings shed light on the tight-knit forces that link changes in strategic action to environmental change, and vice versa.

"Take fish stocks that go up or down depending on the fishing strategies of a population, or soil nutrient levels that go up or down depending on whether there are nitrogen fixers or nonfixing plants present," says Akçay. "How much fish or nitrogen there is will then determine the payoffs from different strategies and favor one or the other strategy. This situation crops up everywhere and while there were disparate models here and there, what Andrew did really was to tie it all together in one. He showed that you can map these models onto a common model and then analyze that model and make predictions for a lot of different systems."

"Understanding how the balance of strategic types in a population impacts the environment, and how the environment then feeds back to alter strategic interactions, is a new challenge for ecologists and behavioral scientists," says Plotkin. "It's a fun theoretical problem, but it also has a host of implications in applied settings, where we increasingly recognize the tight intercalation of human behaviors and the changing environment."

The project arose from Tilman's doctoral work, which looked at the economic incentives people face when dealing with a common-pool resource, for example a fishery or healthy environment.

"I was doing it in an ad hoc way, putting together a model of environmental dynamics with an evolutionary game-theory model for each one," he says. "I was inspired to work on a way to unite many different problems that are all thinking about these strategic interactions linked with a changing environment."

The researchers found that a relatively simple linear model could map the dynamics of a variety of these types of strategy-environment feedbacks.

"We created some nonlinear models as well, and some nuances can arise, but the linear models give you intuition for why those new things can happen," says Akçay. "They're surprisingly powerful."

Their analysis worked for systems like a pollution example, where environmental impact—more pollution—fades as time passes. But the model also fit scenarios where the environmental product regenerated, as in a fisheries example.

The model enabled them to predict how strategies would change, whether they would cycle or achieve an equilibrium, based on the incentives faced by the actors when both the environmental conditions and the strategies in a population were at an extreme. Again turning to the pollution model: "You could imagine that one strategy would be to emit high levels of pollution, and another would be to emit low levels of pollution, and depending on the mix of strategies being used, it will impact the level of pollution that's present," Tilman says. "We can understand what will happen in the game based on how strong the incentives are to switch to a high-pollution strategy when the environment is in a low-pollution state as well as the incentives to switch to a high-polluting strategy when the environment is in a low-polluting state."

The approach sheds light on contemporary issues, such as regulating global emissions in the face of climate change.

"We see that if everything is clean, you want to kill any incentive to be a polluter. Otherwise the cycle could tip back toward polluting strategies," says Akçay.

Looking ahead, the researchers hope to incorporate forecasting into their model. In other words, if an actor can predict how the environment will change, will they alter their strategies earlier or later than they would otherwise?

"These evolutionary and game theoretic models tend to consider the actors to be myopic, switching their strategies based on their instantaneous incentives," says Tilman. "But to more realistically mimic the decision-making processes that people engage in, we want to start thinking about incorporating forecasting into the modeling framework."

More information: Andrew R. Tilman et al, Evolutionary games with environmental feedbacks, *Nature Communications* (2020). DOI: 10.1038/s41467-020-14531-6

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