How a declining environment affects populations

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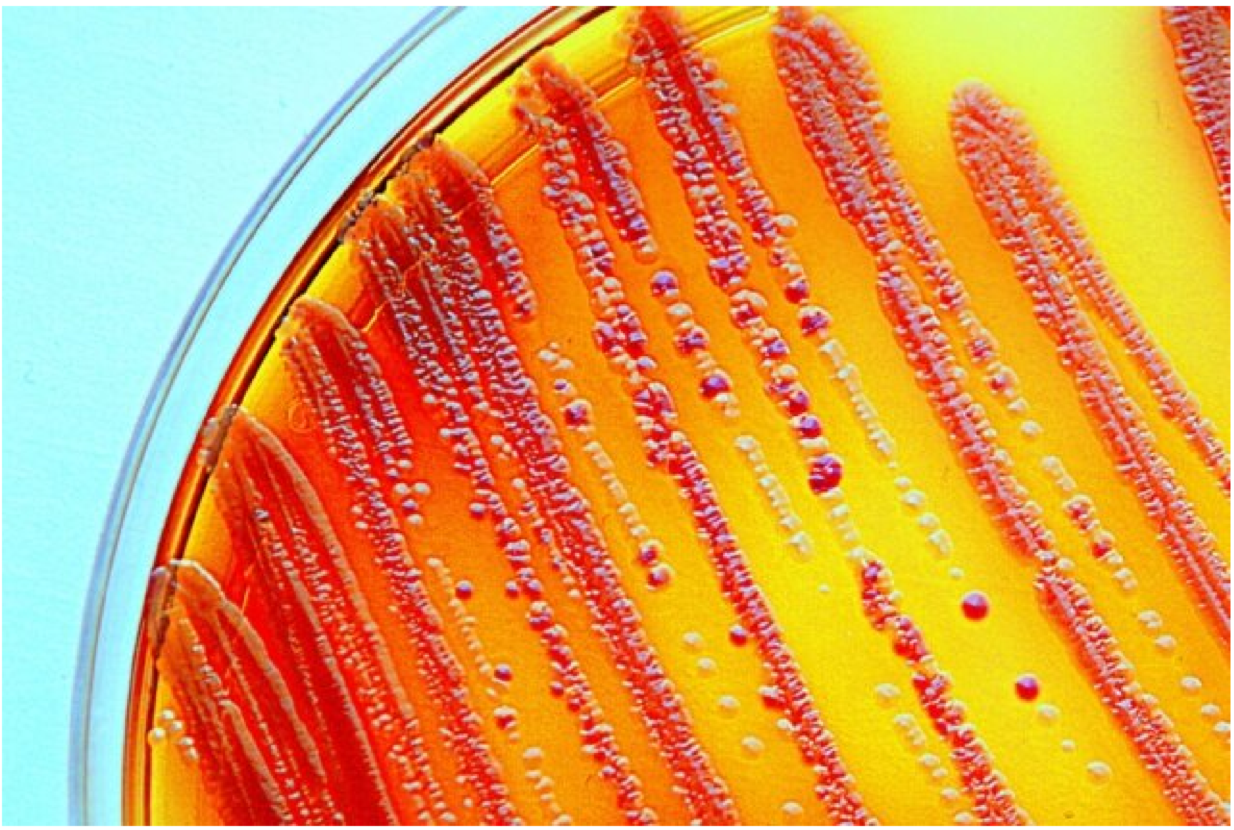

MIT researchers have shown that in microbial communities, bacterial species with a small population size under normal conditions can increase in abundance as environmental conditions deteriorate. Credit: Massachusetts Institute of Technology

Stable ecosystems occasionally experience events that cause widespread death—for example, bacteria in the human gut may be wiped out by antibiotics, or ocean life may be depleted by overfishing. A new study from MIT physicists reveals how these events affect dynamics between different species within a community.

In their studies, performed in bacteria, the researchers found that a species with a small population size under normal conditions can increase in abundance as conditions deteriorate. These findings are consistent with a theoretical model that had been previously developed but has been difficult to test in larger organisms.

"For a single species within a complex community, an increase in mortality doesn't necessarily mean that the net effect is that you're going to be harmed. It could be that although the mortality itself is not good for you, the fact that your competitor species are also experiencing an increase in mortality, and they may be more sensitive to it than you are, means that you could do better," says Jeff Gore, an MIT associate professor of physics and the senior author of the study.

The findings in bacteria may also be applicable to larger organisms in real-world populations, which are much more difficult to study because it is usually impossible to control the conditions of the experiment the way researchers can with bacteria growing in a test tube.

"We think that this may be happening in complex communities in natural environments, but it's hard to do the experiments that are necessary to really nail it down. Whereas in the context of the lab, we can make very clear measurements where you see this effect in a very obvious way," Gore says.

Clare Abreu, an MIT graduate student, is the lead author of the study, which appeared in *Nature Communications* on May 9. Vilhelm Andersen Woltz, an MIT undergraduate, and Jonathan Friedman, a former MIT postdoc, are also authors of the paper.

Competition for resources

Microbial communities, such as those found in soil, oceans, or the human gut, usually contain thousands of different species. Gore's lab is interested in studying the factors that determine which species are present in a given environment, and how the composition of those populations affect their functions, whether that's cycling carbon in the ocean or helping each other resist antibiotic treatment in the gut.

By performing controlled experiments in the lab, Gore hopes to learn how different species interact with each other, and to test hypotheses that predict how populations respond to their environment. In 2013, he discovered early signs that warn of population collapse, in yeast, and he has also studied how different species of bacteria can protect each other against antibiotics.

"We're using experimentally tractable, simple communities to try to determine the principles that determine which species can coexist, and how that changes in different environments," Gore says.

To explore whether these experimental results might be applicable to larger communities, last year Gore and his colleagues published a paper in which they showed that interactions between pairs of species that compete for resources can be used to predict, with about 90 percent accuracy, the outcome when three of the species compete with each other.

In the new study, Gore and Abreu decided to see if they could use pairwise interactions to predict how trios of competing species would respond as environmental conditions deteriorate. To simulate this in the lab, the researchers used the process of dilution—that is, discarding a large percentage (ranging from 90 percent to 99.999999 percent) of the population at the end of each day and transferring the remainder to fresh resources. This could be analogous to real-world conditions such as overfishing or loss of habitat.

"We're trying to get at the general question of how an increase in mortality might change the composition of a community," Gore says.

The researchers studied combinations of five species of soil bacteria. In their experiments, in which they tested pairs of species at a time, they found a specific pattern that fit the predictions made by a classical model of species interactions, known as the Lotka-Volterra model.

According to this model, declining environmental conditions should favor faster growers. The researchers found that this was the case: Even in conditions where a slower grower originally dominated the population, as the dilution rate was increased, the populations shifted until eventually the faster grower either became the larger fraction of the population or took over completely. The final outcome depends on how strong each competitor is, as well as their relative abundance in the starting population.

The researchers also found that the results of the pairwise competitions could accurately predict what would happen when three species grew together in an environment with deteriorating conditions.

"This is an exciting advance in our understanding of microbial ecology," says Sean Gibbons, an assistant professor at the Institute for Systems Biology, who was not involved in the research. "The observation that nonspecific mortality rates can alter competitive outcomes is surprising, although more work needs to be done to understand whether or not dilution is having a more nuanced effect on environmental conditions."

Population models

The Lotka-Volterra model analyzed in this study was originally developed for interactions between larger organisms. Such models are easier to test in microbial populations because it is much easier to control experimental conditions for bacteria than for, say, deer living in a forest.

"There's no particular reason to believe that the models are more applicable to microbes than they are to macroorganisms. It's just that with microbes, we can study hundreds of these communities at a time, and turn the experimental knobs and make clear measurements," Gore says. "With microorganisms, we can arrive at a clear understanding of when is it that these models are working and when is it that they're not."

Gore and his students are now studying how specific environmental changes, including changes in temperature and resources, can alter the composition of microbial communities. They are also working on experimentally manipulating populations that include more than two bacterial species.

More information: Clare I. Abreu et al. Mortality causes universal changes in microbial community composition, *Nature Communications* (2019). DOI: 10.1038/s41467-019-09925-0

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