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The Power of Many - Investigating the Evolution of Cooperation in Bacteria

Cooperation is ubiquitous in nature. Two (or more) parties working together can generate great benefits for both sides, and numerous examples for complex forms of collaboration exist in humans and other animals. Historically, social behaviors were mainly investigated in "higher animals" such as vertebrates and insects. However, by now we have realized that even single-celled bacteria socially engage with each other, and can thus be used to study the evolution of cooperation.

One of the best-studied examples for collaboration among bacteria is the cooperative secretion of molecules. Bacteria produce a number of different substances that are released into the environment to perform a function outside of the cell. The benefits from this process, e.g. nutrient acquisition, can often be accessed by any neighboring cell, effectively rendering the molecule a "public good". We know that these kinds of cooperative systems can be vulnerable to exploitation by "cheats", which do not contribute, but nevertheless reap the benefits of cooperation. How cooperative behaviors evolve in light of this risk of cheating is therefore an important research topic in evolutionary biology.

Due to their short generation times and small size, bacteria are ideal model organisms to study evolution in real-time and in large populations, and modern DNA sequencing technology allows us to elucidate the genetic basis of evolution. We experimentally evolved a cooperative bacterial strain in the laboratory under different conditions to test how natural selection shapes collaborative behaviors, and to investigate how the abiotic environment influences the evolutionary dynamics.

We observed that even in a relatively short amount of time, cooperation was reduced dramatically when the environment allowed newly evolved cheaters to invade. We also found that bacteria sometimes compensated for the loss of a cooperative trait by investing more in another trait, resulting in the evolution of novel behavioral patterns. The abiotic environment also played a crucial role in shaping interactions among evolving bacteria, leading to stark differences in evolutionary trajectories between different environments. Strikingly, some of these highly complex behavioral changes were caused by only a few mutations in key regulatory regions of the bacterial genome.

These results showcase the power of experimental evolution in microbes to elucidate how complex cooperative systems can change and evolve over time, and also demonstrate how interactions among individuals are heavily influenced by their environments.