EVOLUTION

Researchers describe a new evolutionary theory: The Black Queen Hypothesis

BY ROBERT T. GONZALEZ MAR 28, 2012 2:00 PM

Bacteria belonging to the genus *Prochlorococcus* are some of the wimpiest in the world. Left to their own devices, these microorganisms have an exceedingly difficult time just staying alive — which seems counterintuitive, given that they're also the most abundant photosynthesizing organisms on Earth.

Over the course of evolution, these wildly successful bacteria have lost their ability to break down toxic substances like hydrogen peroxide, relying on other organisms to do this work on their behalf. Biological relationships such as these are common in nature, but how they form in the first place is not always clear. Now, researchers have devised a new evolutionary explanation to help explain how these dependencies form. They call it "The Black Queen Hypothesis," and it's every bit as crafty as it sounds.

To many people, evolution is synonymous with an increase in complexity, but there are many examples in nature of organisms evolving to become *less* biologically complicated. Scientists call this "reductive evolution."

Reductive evolution is often observed in parasites. A tapeworm that wriggles around your insides and absorbs all its nutrients through its skin, for example, has no need for a digestive tract. After all, maintaining an unnecessary biological function is energetically costly; the tapeworm has nothing to lose (and resources to gain) by ditching its digestive tract altogether.

A similar process can be observed in various parasitic species of bacteria, which will shed metabolic functions (and their associated genes) left and right, provided there's a host nearby to pick up the biological slack. This type of reductive evolution is most typically caused by what biologists call genetic drift — random genetic mutations that arise within a species when an organism is isolated from the outside world and its population levels are low, two prominent features of the parasitic lifestyle. But organisms belonging to the genus *Prochlorococcus* are what biologists call "free-living" bacteria, meaning they aren't parasitic. So how, exactly, did these microorganisms become so dependent upon their fellow microbes for survival?

The answer may lie in what biologist Jeff Morris calls the Black Queen Hypothesis. He and his colleagues describe the reasoning behind this novel evolutionary theory in the latest issue of *mBio*:

> [The Black Queen Hypothesis] refers to a playing card, in this case the queen of spades in the game Hearts. In Hearts the goal is to score as few points as possible. The queen of spades, however, is worth as many points as all other cards combined, and therefore a central goal of the game is to not be the player that ends up with that card.
>
> In the context of evolution, the BQH posits that certain genes, or more broadly, biological functions, are analogous to the queen of spades. Such functions are costly and therefore undesirable, leading to a selective advantage for organisms that stop performing them. At the same time, the function must provide an indispensable public good, necessitating its retention by at least a subset of the individuals in the community — after all, one cannot play Hearts without a queen of spades.

In the context of *Prochlorococcus*, the "public good" that is being provided by the supporting microbes is the breakdown of toxic hydrogen peroxide. This is what biologists call a "leaky" genetic function, because it serves to benefit any life form in the vicinity of the organism doing the work.

If the consequences of the Black Queen Hypothesis sound similar to those of the parasitic relationships mentioned earlier, that's because they are, save for two very important points:

1) In the Black Queen Hypothesis, reductive evolution is driven not by genetic drift (i.e. chance), but by natural selection; so long as the benefit gained by losing a gene outweighs the cost of no longer having it (a benefit ensured by the presence of other, leaky organisms), the loss of that gene will continue to spread throughout the population.

2) There's nothing about the Black Queen Hypothesis that says the organism contributing the "leaky" genetic function is sacrificing its fitness, as is the case in parasite/host relationships.

These are subtle differences, but they're significant ones. Most people are familiar with the concept of parasitism, whereby one organism benefits at the other's expense. Many people are also familiar with the idea of symbiosis, which is used to describe a mutually beneficial relationship between two different organisms. Parasitism and symbiosis are both examples of what are called biological interactions. (People tend to be less familiar with biological interactions like commensalism, wherein one organism benefits and the other derives neither benefit nor harm. Read more about biological interactions here). The issue here, explains Morris, is how different forms of biological interaction arise; the Black Queen Hypothesis, he says, doesn't describe a *type* of interaction, but rather how these interactions can evolve:

> Black Queen, like the Red Queen Hypothesis (which describes "arms races" between predators/prey, hosts/parasites, and so forth), can lead to all three of the primary kinds of relationships: parasitism, commensalism, mutualism. It all depends on the specific conditions under which the organisms are growing and interacting. The big difference is that Red Queen focuses on a sort of "active" evolution, where one might imagine that species are racing to gain abilities that will give them an edge over their competitors or predators.

The Black Queen Hypothesis, in contrast, is a much more passive affair. "Species are in a 'race to the bottom' to get rid of as many costly functions as they can get away with," says Morris.

"It's all about what you don't do — about a loss of complexity, which is sort of backward from the way people typically think about evolution."

Morris and his colleagues' description of the Black Queen Hypothesis is published in the latest issue of *mBio* (no subscription required).
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So I guess one way to interpret this is organisms that are examples of the BQH are, in a sense, parasitic on the whole ecosystem they find themselves in. By my understanding the reductive evolution we see happening in these cases is only possible if the diversity of organisms in ecosystem is sufficiently complex enough to outsource jobs to?

Would the BQH work in a simple ecosystems where the points of failure are more exposed and less robust?

Morne @corpore-metal

Actually if I'm reading this right it looks like they could also be commensal (or however you say "in a commensalism relationship"). Because the ones not producing hydrogen peroxide or whatever aren't hurting the ones that are in any way; they just derive a benefit from it. Or it could be parasitic if the desired product was in limited demand.

And I cannot comment with any knowledge on the BQH, but generally all systems with less biodiversity are considered less stable, no? But isn't it theoretically possible for this to occur with just two species? Say, a couple kinds of bacteria that both live in the same location, both producing some necessary chemical, and then one of those species stops producing it, thereby becoming dependent on the other species.

nahde @Morne

well, technically you're both right. The latter paragraphs mention this process doesn't promote either of those, nor does it promote symbiosis. Rather, its just a way to explain how those relationships arise. The organism dropping a gene to let another species perform it doesn't really promote any 3, but it can give rise to any of those 3. Take the above example... it can be any 3.

Parasite:
The bacteria breaking down the chemical might die quicker or divide less frequently the more they do the act. In which case the one losing the genes are benefiting at the expense of the other.

Commensalism:
If the breakdown doesnt cost the bacteria keeping the gene but for the other organism gets to drop a complex mechanism.

Symbiosis:
The one breaking down gets some sort of resource (nutrients, energy, etc) from the breakdown but for the other bacteria, doing the breakdown is more costly than the benefits.

promoted by corpore-metal

corpore-metal @Morne

I don't really know either. I was just trying to look at the BQH from a systems level rather just at the level of individual organisms. I just wonder if we can find examples of BQH in, say, the oceans of the Arctic or Antarctic. There the ecosystems are deceptively simple. Maybe it wouldn't work there.

Again, I don't really know. This is just questions and speculation.

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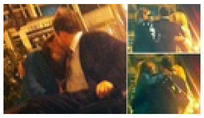

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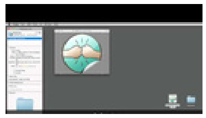

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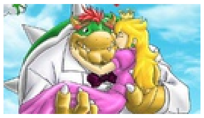

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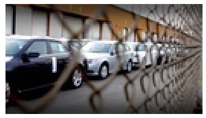

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