Why Do Cave Fish Lose Their Eyes?

How evolution can lead to losing abilities as well as gaining them

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There are caves deep under the ground where the sun never shines. The only light that enters these caves is from the headlamps of cave explorers. If you went inside of one of these caves and turned off your headlamp, you would see nothing at all. There would be no shadows or shapes, just blackness.

Carlsbad Caverns National Park

In some of these caves, there are organisms that live without light. They include salamanders, crustaceans, and fishes. In fact, more than one hundred species of cave fishes live in darkness for their whole lives. They depend on senses other than sight to hunt, eat, and reproduce. These fishes have evolved, or developed over many generations, to live without light.

Many of these species of fishes are blind or nearly blind. Some of them don't even have eyes. Yet they all evolved from fishes that could see. Somehow, over millions of years, these fishes both lost the ability to see and gained the ability to live without sight.

How did that happen? How can evolution cause a species to lose a trait? It's a mystery that scientists have been trying to solve. Their search for an answer gives us a fascinating look at how evolution works.

Regressive Evolution

We usually think of evolution as a process in which species gain new traits. But in cave fishes we have an example of regressive evolution. Regressive means "going backward," and regressive evolution is a process in which species lose a trait. In this case, that trait is the ability to see.

Blind cave fish in Mammoth Cave National Park, Kentucky

A common belief is that the ancestors of cave fishes went blind in their evolution because they didn't use their eyes. This idea might seem to make sense at first, but it has no basis in science. Genes determine which traits are inherited. For example, the fact that you have five fingers on each hand is because of the genes you inherited from your parents. However, if you lose a finger in an accident, your children will still be born with five fingers on each hand. If you lift weights and become a body builder, it doesn't mean your children will be born with big muscles. In each of these examples, your body has changed, but your genes haven't.

Darwin Is Stumped

The fact that the ancestors of cave fishes didn't use their eyes had no effect on their genes. Yet at some point in the past, something clearly happened to their genes that stopped the development of their eyes. This new condition passed on from parent to offspring. How can this sort of regressive evolution be explained?

Even the scientist who established a modern understanding of evolution had trouble answering this question. That scientist was Charles Darwin, who lived in the 19th century. At the time when he was born, DNA hadn't been discovered, so he didn't know about genes or their role in the inheritance of traits. But he understood that traits were inherited. He also knew that differences within a species give some individuals an advantage over others. Animals with traits that make them more successful at having offspring will pass on those traits to the following generations. He called this process evolution by natural selection.

However, Darwin had trouble applying his theory of natural selection to the question of why some cave fishes are blind. He could not explain how being blind gave those cave fishes an advantage. And if being blind is not an advantage, then how did natural selection lead to a species of blind cave fish? Darwin's answer was that cave fishes lost their eyes because they didn't use them. His answer was a Lamarckian explanation. Today, scientists know that this explanation is wrong.

Lamarck's Mistake

Jean-Baptiste Lamarck was a scientist who lived from 1744 to 1829. He started coming up with theories of how evolution worked at a time when most people did not even accept the idea of evolution. He tried to explain how species evolved, but he came to the wrong conclusion. He thought that traits gained during an animal's lifetime could be passed down to its offspring. For example, he suggested that giraffes stretched their necks to reach higher leaves, and as a result their offspring were born with longer necks. The idea that cave fishes lost their eyesight because generations of fish didn't use their eyes is a Lamarckian mistake.

Two Answers

Most of what we know now is based on the study of one species of cave fish. This species is the Mexican tetra. Scientists after Darwin have come up with two possible explanations for blindness in this cave fish. The explanations probably apply to other cave fishes as well.

Mexican tetra

The first hypothesis is that blindness gives the fish an evolutionary advantage. For example, it's possible that changes in the gene or genes that cause blindness also cause some other change in the fish that is helpful. Scientists call changes in genes "mutations." Scientists also have a word for when the same mutation in one gene has more than one effect. That word is pleiotropy. To support the first hypothesis, scientists would have to look for some advantage to the fish that is connected with the same mutation that causes blindness.

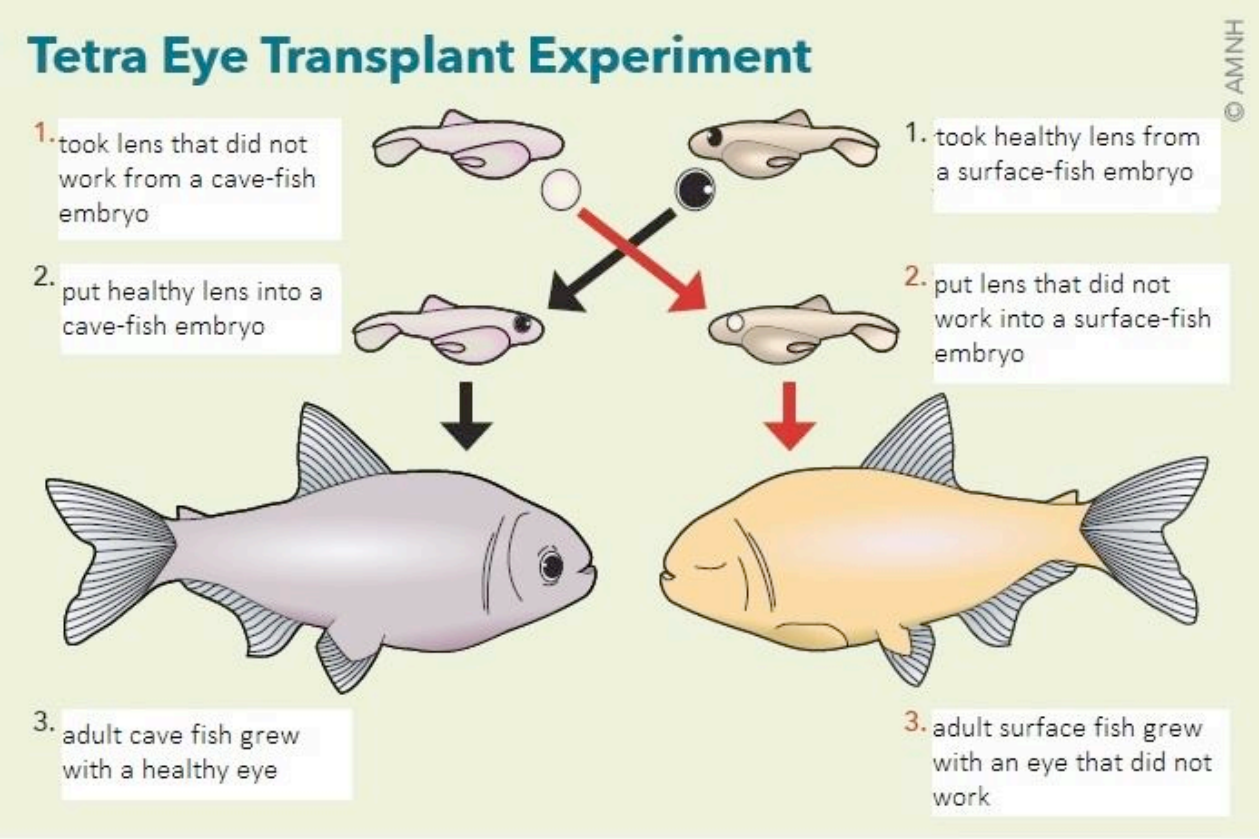
The second hypothesis that could explain blindness in the cave fish also has to do with evolution. Natural selection does not just reward success and preserve traits that give some animals an advantage. It also gets rid of failures. To understand the second hypothesis, picture a lake where there is sunlight. In this lake, a fish that is born blind would have trouble competing with other fish that can see. It probably would not survive to have offspring. But a fish that is born blind in the water of a dark cave would not be at a disadvantage compared to a fish that can see. That is because eyes are useless in the dark. In such an environment, natural selection will not work to get rid of the mutation for blindness. Over one to two million years, many more mutations interfering with the development of eyes will occur and add up. After a while, the whole population of fish in the cave will be blind. This is called the neutral mutation hypothesis. It is based on the idea that the mutations that cause blindness have a neutral effect (an effect that is neither good nor bad) on the survival of a fish living in a dark cave.

An Eye-Opening Experiment

A group of scientists set out to study the causes of blindness in the cave fish. They carried out an experiment with two varieties of the same species of Mexican tetras. One variety of tetras lives near the surface of water that gets sunlight. This variety can see. The other variety lives in water in dark caves and is blind.

The scientists took a lens from the eye of a surface tetra embryo and put it into the eye of a cave tetra embryo. The result was striking. The new lens in the cave tetra caused all of the

tissues around it to develop into a healthy eye. This experiment showed that even though the eye of the tetra had stopped working, the genes involved in eye development still worked.



This result suggests that the neutral mutation hypothesis is wrong, because if blindness were caused by many neutral mutations adding up over time, the new lens would not have resulted in the development of a healthy eye. The scientists knew that there are many genes in charge of the development of each part of an eye—such as the lens, the iris, and the retina. The scientists also knew that each part of the eye develops on its own. However, the results of the experiment showed that blindness in the cave tetra was not due to mutations in all those genes. Instead, it suggested a small number of mutations in genetic "master switches." These master switches are genes that control the function of many other genes. In this case, some of the genes controlled by the master switches were in charge of eye development. These "master switches" can deactivate the eye genes so that the genes are still intact but not doing anything. Putting a healthy lens into the cave tetra embryo seems to cause master switches to send a signal to the deactivated eye genes. The eye genes are then "turned on," and the cave tetra develops eyes. If the scientists could find the master switches that made cave tetras blind, they could find out whether the same switches had effects on other traits of the fish that do give it an evolutionary advantage for surviving in caves.

The scientists did indeed find one of those genes. It is nicknamed *Hedgehog* or the *Hh* gene. They discovered that this gene does more than cause blindness in cave tetras. When the fish develops without eyes, the skull bones move into the empty eye sockets. When the bones move into the eye sockets, the fish's nose becomes bigger. In this way, it could be that the same master switch (the *Hh* gene) that stops eye development in the fish is also responsible for improving its sense of smell. An improved sense of smell would be an advantage for a fish that lives in the dark.

As a result of this experiment and others, it now seems likely that blindness in cave tetras is in part the result of pleiotropy. That is because the same mutation in one gene (the master switch) has more than one effect (blindness and an improved sense of smell).

Evolution Works

Scientists are still studying cave fishes, and new discoveries are sure to be made. But it is already clear where the answers to their questions will be found. The answers will be found in the basic processes of evolution that are already well understood. With new tools that give scientists the ability to map genes, find mutations, and understand the development of embryos, we are increasing our understanding of how evolution works.