

Why Do Cave Fish Lose Their Eyes?

by American Museum of Natural History
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How evolution can lead to losing abilities as well as gaining them

Deep underground there are caves where the sun never shines. The only light that enters these subterranean spaces is from

the headlamps of occasional cave explorers. If you found yourself in one of these caverns and turned off your headlamp, you would see nothing at all; no shadows, no shapes, just total blackness.

In some of these underground caves, there are fishes, crustaceans, salamanders and other organisms that have evolved to live without light. For example, more than one hundred species of cave fishes live their lives in perpetual darkness. They depend on senses other than sight to hunt, eat and reproduce.

Many of these species of fishes are blind or nearly blind-some don't even have eyes. Yet they all evolved from fishes that could see. Somehow, over millions of years, these fishes not only acquired the ability to live without sight-they lost the ability to see altogether.

How did that happen? How can evolution cause a species to lose a trait? It's a mystery that evolutionary scientists have been struggling to unravel, and the search for an answer gives us a fascinating look at how evolution works.

Regressive Evolution

We usually think of evolution in a positive sense, that is, as a process in which species acquire new traits. But in cave fishes we have an example of regressive evolution, a process in which species lose a trait -in this case, the ability to see.

A common assumption is that the ancestors of cave fishes went blind in their evolution because they didn't use their eyes. Though at first this idea might seem to make sense, it actually has no basis in science. Genes determine the inheritance of traits. For example, the fact that you have five fingers on each hand is because of the genes you inherited from your parents.



Carlsbad Caverns National Park



Blind cave fish, Mammoth Cave National Park, Kentucky

However, if you have an accident and lose a finger, 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 bulging biceps. In each case, your genes haven't changed—even though your body has.

Darwin Is Stumped

The fact that cave fishes' ancestors didn't use their eyes had absolutely no effect on the DNA in their chromosomes. Yet clearly, at some point in the past something 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?

Charles Darwin himself, the scientist who first established a modern understanding of evolution, had trouble answering

this question. Darwin lived in the 19th century when DNA hadn't been discovered and so he didn't know about genes or their role in heredity. But he understood that traits were inherited and 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 succeeding generations. He called this process evolution by natural selection.

However, Darwin had trouble applying his theory of natural selection to the problem 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? Surprisingly, Darwin was convinced that the loss of eyes could be explained entirely to disuse, which is in fact a Lamarckian explanation. Today, scientists know that this explanation is unfounded.

Two Hypotheses

Most of what we know now is based on the study of the blind Mexican tetra (*Astyanax mexicanus*). Scientists have two competing explanations for blindness in the Mexican tetra, which likely apply in other cave fishes as well.

The first hypothesis assumes that blindness gives the fish some sort of evolutionary advantage. For example, it's possible

Lamarck's Mistake

Jean-Baptiste Lamarck was a French naturalist who lived from 1744 to 1829. He was a pioneer developing theories of evolution at a time when the very idea of evolution was not accepted. Lamarck tried to explain how species evolved but came to an incorrect conclusion—that traits acquired during an organism'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.



that changes in the gene or genes that cause blindness are also responsible for some other seemingly unrelated change in the fish that is beneficial. Scientists call this pleiotropy—when multiple effects are caused by the same mutation in one gene. To support this hypothesis, scientists would have to look for some advantage to the cave fish that is linked to the same mutation that causes blindness.

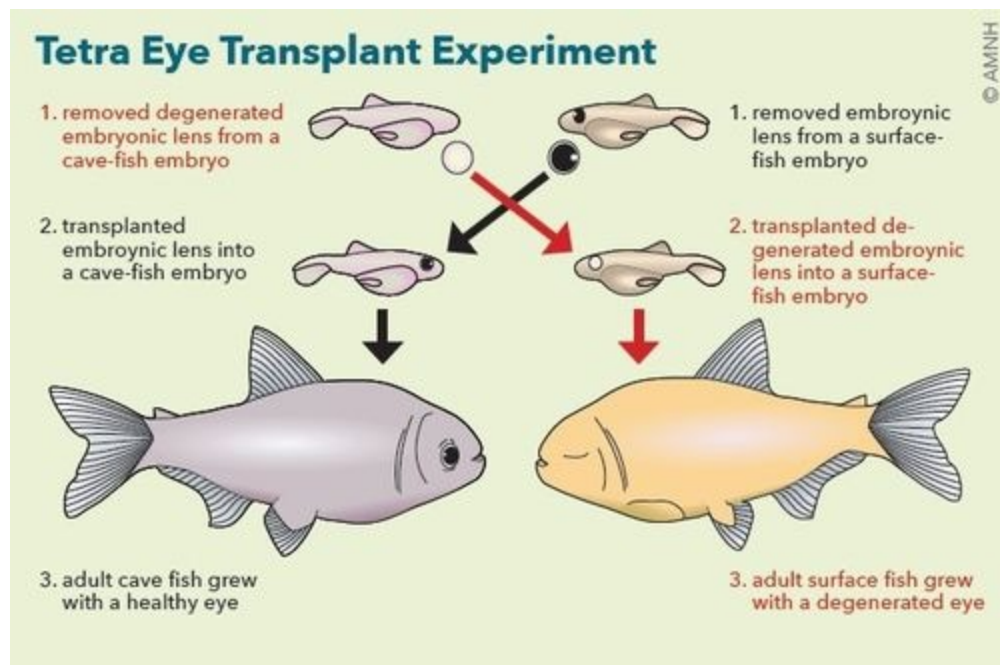
Mexican tetra (Astyanax mexicanus).

The second hypothesis that could explain blindness in the cave fish is based on the fact that natural selection does not just reward success, it also weeds out failures. In a lake, where there is sunlight, a fish born blind would have trouble competing with other fish that can see. It probably would not survive to have offspring. But a fish born blind in a dark cave would not be at a disadvantage, since in the darkness eyes are useless. In those conditions, natural selection will not work to weed out the mutation for blindness. Over one to two million years, many more mutations disrupting the development of the eyes will accumulate and eventually the entire population of fish will be blind. This is called the neutral mutation hypothesis, based on the idea that the mutations for causing blindness have no effect (or have a neutral effect) on the survival of the fish living in a dark cave.

An Eye-Opening Experiment

A group of scientists at the University of Maryland set out to investigate the developmental causes of blindness in the cave fish. They carried out an experiment with two varieties of the same species of Mexican tetras. One variety lives in bodies of water near the surface where there is sunlight and can see. The other variety of tetras lives in dark caves and is blind.

The scientists transplanted a lens from the eye of a surface tetra embryo into the eye of a cave tetra embryo. The result was striking—the surface tetra lens transplanted into the cave tetra caused all of the surrounding tissues to develop into a healthy eye. This experiment demonstrated that despite the degeneration of the eye in the tetra, the genes involved in eye development were still totally functional. This would seem to rule out the neutral mutation theory because, if blindness were caused by an accumulation of many neutral mutations over time, the transplant would not have resulted in the development of a healthy eye. The scientists knew that there are many genes responsible for the development of each part of an eye (for example, the retina, iris, cornea and lens), which develops independently. However, the results of the experiment showed that blindness in the Mexican 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, including, in this case, those responsible for eye development. These "master switches" have the ability to disable the eye genes so that these remain intact, but inactive. Putting a healthy lens into the cave tetra embryo seems to trigger master switches to send a signal to the inactive eye genes, allowing cave tetras to develop eyes.



If scientists could find the genetic "master switches" that made cave tetras blind, they could discover if the same switches had effects on other traits of the fish that do give it an evolutionary advantage for surviving in caves.

The researchers did indeed find one of those genes. It is nicknamed Hedgehog or the Hh gene. They discovered that the Hedgehog gene does more than cause blindness in cave tetras-when the fish develops without eyes, the skull bones move into the empty eye socket, which at the same time enlarges the nose. Unlike other vertebrates, fishes use their nose only for smelling. It could be that the same control gene (Hh) that stops eye development in the fish also is responsible for enhancing its sense of smell. An enhanced sense of smell would be a definite advantage for a fish that lives in darkness.

As a result of these and other experiments, it now seems highly likely that blindness in cave tetras is in part the result of pleiotropy-one mutation that causes blindness in the fish and at the same time, gives them an enhanced sense of smell.

Evolution Works

Scientists are still studying cave fishes, and new discoveries are sure to be found. But one thing is already clear-the answer lies in the basic processes of evolution that are already well understood. With new tools that give scientists the ability to map genes, find specific mutations, and understand the development of embryos, we are increasing our understanding of how evolution works.

Name: _____ Date: _____

1. What ability have many cave fishes lost?

- A. the ability to swim
- B. the ability to smell
- C. the ability to see
- D. the ability to hear

2. To organize this text, the author divides it into sections with subheadings. What is described in the section with the subheading "Darwin Is Stumped"?

- A. Darwin's understanding of evolution and his explanation of blindness in cave fishes
- B. Darwin's daily life in the 19th century and the places where he studied blindness in cave fishes
- C. the animals Darwin studied as a young man that led him to develop his theory of evolution
- D. the objections that have been raised to the theory of evolution developed by Darwin

3. An organism's genes determine which traits it inherits.

What evidence in the article supports this statement?

- A. "In some of these underground caves, there are fishes, crustaceans, salamanders and other organisms that have evolved to live without light. For example, more than one hundred species of cave fishes live their lives in perpetual darkness. They depend on senses other than sight to hunt, eat and reproduce."
- B. "We usually think of evolution in a positive sense, that is, as a process in which species acquire new traits. But in cave fishes we have an example of regressive evolution, a process in which species lose a trait—in this case, the ability to see."
- C. "...if you have an accident and lose a finger, 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 bulging biceps. In each case, your genes haven't changed—even though your body has."
- D. "Jean-Baptiste Lamarck... 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."

4. Based on the information about evolution in this text, what effect does the trait of blindness have on a fish living in a dark cave?
- A. The trait of blindness has a positive effect; it gives the fish an evolutionary advantage.
 - B. The trait of blindness has a negative effect; it puts the fish at an evolutionary disadvantage.
 - C. The trait of blindness has a neutral effect; it is neither an advantage nor a disadvantage.
 - D. The trait of blindness has a mixed effect; it is an advantage for the fish at certain times and a disadvantage at other times.
5. What is the main idea of this text?
- A. There are caves deep underground where the sun never shines, and in some of these underground caves, there are fishes, crustaceans, salamanders, and other organisms that have evolved over many years to live without light.
 - B. Charles Darwin was a scientist living in the 19th century who was convinced that cave fishes lost their eyesight because they did not use their eyes.
 - C. The neutral mutation hypothesis about the blindness of cave fishes is based on the idea that the mutations that cause blindness have no effect (or a neutral effect) on the survival of a fish living in a dark cave.
 - D. Many cave fishes are blind, and an experiment carried out by scientists suggests that blindness in these fishes is the result of a mutation that also improves their sense of smell.
6. The title of this text is "Why Do Cave Fish Lose Their Eyes?" Why might the author have written the title as a question?
- A. to encourage readers to answer the question on their own before they read the article
 - B. to prepare readers for a discussion of possible answers to this question in the article
 - C. to criticize scientists for not having reached a definite answer about why cave fishes lose their eyes
 - D. to praise scientists for the effort they have put into understanding the cause of blindness in cave fishes

7. Choose the answer that best completes the sentence.

Many species of cave fishes are blind or nearly blind. _____, they all evolved from fishes that could see.

- A. Consequently
- B. Primarily
- C. However
- D. For instance

8. Describe the first hypothesis that scientists have about blindness in the Mexican tetra. Be sure to discuss pleiotropy in your answer.

9. One effect of the Hedgehog gene is to make cave tetras go blind. What is another effect it might have?

10. As a result of the experiment scientists did with Mexican tetras, it seems likely that their first hypothesis about blindness in the tetras is right. Explain how the result of the experiment supports their first hypothesis.

Support your answer with evidence from the text.