

## *The Making of the Fittest: The Birth and Death of Genes*

**[NARRATOR:]** For life to survive, it must adapt and re-adapt to an ever-changing Earth. New traits and capabilities must be invented. While some traits may be lost. To see one of the most dramatic examples of how this occurs, we will follow a voyage of long ago, that will take us 1600 miles off the southern tip of Africa to one of the most remote places on the planet--Bouvet Island. A speck at the edge of the Antarctic, it's pummeled by waters so wild that getting there was no sure bet, especially in 1927, when this Norwegian steamship left port.

**[DR. CARROLL:]** It's cold. It's windy. It's rough waters. They're far away from civilization, so it was a really long and arduous voyage from Norway to eventually the shores of Bouvet Island.

**[NARRATOR:]** Norway had dispatched the expedition to claim the island as an outpost for its whalers. And after two months at sea, on December 1st, the crew finally rowed ashore, and erected the Norwegian flag. But that's not the most important achievement of this expedition.

**[DR. CARROLL:]** One aspect of their voyage was to understand all the sea life that was there. And so, there was a zoologist on board, Ditlef Rustad. And Ditlef's job was to really just throw a net over the side and trawl up, see what he found. But one day, in fact, the day after Christmas, 1927, he pulls up a really unusual-looking fish.

**[NARRATOR:]** A creature that many years later would illuminate our understanding of how evolution works. A creature so unexpected it is still barely believable today when taken from a freezer at Northeastern University by a biologist who has spent much of his career trying to make sense of it.

**[DR. DETRICH:]** Well Sean, it's easy to see why the fish was originally called the crocodile fish. Notice the very big protruding jaw with lots of teeth.

**[DR. CARROLL:]** Incredible. But it's so translucent, it seems like I can see inside the fish.

**[DR. DETRICH:]** Well the reason you can see inside the fish is that this is a scaleless fish, and in fact, if you...

**[DR. CARROLL:]** What is that?

**[DR. DETRICH:]** Well, that's the brain.

**[DR. CARROLL:]** My goodness

**[DR. DETRICH:]** You can actually see the brain through the skull. And you can also see projecting from the brain the optic nerves going over to the eyes. And Sean, for comparison, we can take a look at a cod, and when I pull back the gills of the crocodile fish...

**[DR. CARROLL:]** Creamy white, look at that.

[DR. DETRICH:] And here if we take a look at the cod...

[DR. CARROLL:] Oh, brilliant red.

[DR. DETRICH:] Yeah, very, very red.

[DR. CARROLL:] So that would have surprised Rustad, because all the other fish he had seen would have had red gills.

[DR. DETRICH:] Absolutely.

[NARRATOR:] But that wasn't the most incredible thing about Rustad's find. That came to light when Rustad, like any good Norwegian confronted with a strange fish, filleted it, as I'm doing today, under Bill Detrich's watchful eye.

[DR. CARROLL:] Unbelievable. Everything's white. Everything's colorless. All the organs. All the soft tissue. The heart even. Every other fish he had opened in his life was full of red blood, but not this fish. And he wrote in his notebook, boldly, colorless blood, "blod farvelost."

[NARRATOR:] The crocodile fish or icefish, as they've come to be known, had a dilute liquid almost as clear as ice water flowing through its veins.

[DR. DETRICH:] And, here is your icefish blood.

[DR. CARROLL:] That's amazing.

[NARRATOR:] Except for the icefish, all of the vertebrates on Earth--reptiles, birds, mammals, and all other fish, like this cod--have red blood coursing through their veins.

[DR. CARROLL:] So, what's so incredible about having no red blood cells at all is that--for example, our blood, 45 percent of our blood by volume is red blood cells. So, we have enormous numbers of red blood cells in our blood, as do most other backboned animals. And when our red blood cell count decreases a little bit, we call that anemia. And if it decreases a lot, that's life-threatening. So, it's stunning that an animal could get by with no red blood cells at all.

[NARRATOR:] Why would a fish abandon a way of life that had nourished its ancestors for 500 million years? It has to do with the extreme habitat in which it lives.

[DR. DETRICH:] The more cells that are present in blood, the thicker it becomes at cold temperatures.

[DR. CARROLL:] So this watery blood allows the fish to live in really cold temperatures. So if it had blood like this, it'd be all gummed up?

[DR. DETRICH:] That's correct.

**[DR. CARROLL:]** Alright.

**[NARRATOR:]** Blood is red because it contains hemoglobin, the protein that delivers oxygen throughout the body. Yet the icefish have not one hemoglobin molecule. The fish absorb enough oxygen from the sea through their scaleless skin, so that they can make do without hemoglobin. But the lack of red blood cells still doesn't fully explain how any blood flows in oceans this cold: below the freezing point of fresh water and almost at the freezing point of seawater.

**[DR. CHENG:]** And fish cannot live generally in that sort of environment because their freezing point of the blood is higher than the freezing point of sea water.

**[NARRATOR:]** Yet fish thrive in these waters, icefish and other species--all members of a group called the Notothenioids. To show just how different Antarctic notothenioids are from other fish, husband and wife biologists Arthur DeVries and Christina Cheng dunk one in water as icy as the ocean outside their lab on Antarctica's McMurdo Sound. The temperature--minus 1.8 degrees Celsius--is so cold, it's below the freezing point of fresh water, and blood.

**[DR. DEVRIES:]** So as you can see, this fish is doing fine, at this freezing temperature in the midst of ice crystals.

**[NARRATOR:]** How these fish thrive in such cold waters baffled scientists, until the 1960's, when Art DeVries found that Antarctic fish had invented something that protects them from freezing--anti-freeze.

**[DR. CHENG:]** These fish have a certain protein. And what it does is bind to the ice crystal in the fish and by binding to it, and preventing it from growing any bigger, the fish doesn't freeze.

**[DR. CARROLL:]** So, only one group of fish in the Southern Ocean--the Notothenioids, icefish belong to that group--have anti-freeze. So, it's an invention unique to this group. And that's allowed those fish to invade a space that other fish couldn't live in. And these are nutrient-rich waters, full of lots of food. So, these fish are thriving now where other fish couldn't thrive.

**[NARRATOR:]** Anti-freeze proteins give Notothenioids a clear edge where they live. But their existence poses an evolutionary mystery--when and how was anti-freeze invented? The waters around Antarctica were once a temperate 10 degrees Celsius. But 34 million years ago, Drake Passage opened as Antarctica broke away from South America. Now a continuous current circled the new continent, isolating its surrounding waters. As a result, those waters chilled to minus 1.8 degrees Celsius. So Notothenioids and anti-freeze evolved in the last 34 million years. But traits are encoded by genes. Where did anti-freeze genes come from? DeVries, Cheng, and Liangbiao Chen worked out part of the mystery in the 1990s by noticing that parts of the anti-freeze gene, labeled in red, strongly resembled a different gene. That one gene gave rise to the other. The process began when the ancestral gene was accidentally duplicated. While one copy remained the same, the other accumulated mutations, that eventually gave it a new function--to make anti-freeze proteins.

**[DR. CARROLL:]** The invention of anti-freeze is a crystal-clear example of inventing something new from something old, borrowing, sort of, the code of a preexisting gene, and then altering that to create a protein that has entirely new functions. And this story we see again and again in evolution, inventing something new from the old.

**[NARRATOR:]** Notothenioids invented anti-freeze genes, but one family, the icefish, went a step further and eliminated red blood cells and hemoglobin altogether. As for how that happened, the answer has also been preserved in DNA. And Bill Detrich found it when he compared globin genes from icefish and other fish. Globin genes encode the hemoglobin protein.

**[DR. CARROLL:]** So what do we see here?

**[DR. DETRICH:]** Well, as you go from left to right here, the normal red-blooded globin gene is shown in the sequence on the top. Down below, we have the sequence of the icefish. And as we move from the left you can see there are dots. These are exact matches in the sequence. However, at the arrow we see that we get virtually no match. This is essentially genetic gibberish.

**[DR. CARROLL:]** So it's broken right there?

**[DR. DETRICH:]** That is exactly right.

**[NARRATOR:]** At some point in history, a mutation wrecked this gene. And since hemoglobin was no longer necessary to icefish, the mutation wasn't weeded out.

**[DR. DETRICH:]** And this is the fossilized remnants of that gene.

**[DR. CARROLL:]** So if the gene has become useless, it will eventually be lost as these mutations pile up and just erase what used to be there?

**[DR. DETRICH:]** That is exactly right.

**[NARRATOR:]** So genes are born and genes die, as species find ways to survive in an ever-changing world.

**[DR. CARROLL:]** What this remarkable fish that Ditlef Rustad dredged up 80 years ago has taught us is that evolution doesn't always come up with the best solution imaginable, it just comes up with the best solution available. And that sometimes means getting rid of things that worked in our ancestors, as well as inventing new things like the anti-freeze. And that record of changing habitats and changing lifestyles and changing genes is etched in the DNA record of life.