Marine Adaptation

Surviving in Near-Freezing Water

Approximately 32 million years ago, the continent of Antarctica began to separate from South America. This event resulted in the opening of the Drake Passage and formation of an Antarctic Circumpolar Current that resulted in the rapid cooling of Antarctic waters. Temperatures plunged from around +10°C to the current summer to winter range of +1.5°C to -1.8°C. Marine invertebrates were able to survive these changes because their bodies contain the same concentration of salts and minerals as that of the surrounding seawater, as well as a variety of organic compounds that depress the freezing point of their body fluids. In contrast, the body fluids of marine fish are more dilute than seawater and freeze at approximately -0.8°C. Temperature changes of this magnitude, therefore, had a great impact on the preexisting fish fauna. From what we know about fossil record, it is clear that most of the fish fauna did not survive.

Today, about 322 species of fish inhabit the seas around Antarctica and about 35% of those species are members of just six families of the ray-finned fish suborder Notothenioidei. Notothenioids have been so successful that they now make up approximately 90% of the fish biomass in Antarctic seas. How did these Notothenioids become so dominant? It was probably due to both the development of a series of adaptations that allowed survival in these icy waters and a lack of competition from those species that could not. These adaptations and lack of competition allowed this group to experience extensive radiation over the past 24 million years.

The first adaptive innovation, and possibly the most important, was the development of antifreeze glycoproteins. These glycoproteins (molecules composed of sugar and protein) protect cells by lowering the temperature at which ice crystals enlarge. AT these temperatures, if an ice crystal were event to brush a fish’s skin, it would quickly propagate and pierce the skin like a spear. The development of antifreeze glycoproteins itself makes an interesting story in molecular evolution. They seem to have been derived by chance modification of the preexisting gene sequence that encoded messenger RNA (mRNA) for pancreatic trypsinogen, an enzyme involved in digestion. It has been postulated that an early version of this gene may have first functioned in preventing freezing of intestinal fluid. Later, expression of this gene in the liver expanded its function to the circulatory system.

All animals require oxygen to survive. In most vertebrates, oxygen is primarily transported to the tissues bound to molecules of hemoglobin located in red blood cells. In humans, these red blood cells make up about 45% of the blood’s volume. The low temperatures of Antarctic waters, however, would make blood with that high a cell volume far too viscous to flow efficiently. To compensate for this “sludge” factor, all Notothenioids have a reduced number of red blood cells and a lower concentration of hemoglobin molecules in comparison to their temperate and tropical relatives. One family of Notothenioids, the crocodile icefish (family Channichthyidae), has lost red blood cells and hemoglobin entirely. Indeed, most of the gene sequence that encodes hemoglobin has been deleted from their genome. Notothenioids (including the icefish) also have lost myoglobin (a molecule that stores oxygen) from their skeletal muscles but, with the exception of six icefish species, most retain it in the ventricle of the heart.

How are icefish able to survive without hemoglobin? One of the reasons the 16 species of icefish are able to survive is because water is maximally saturated with oxygen at these low temperatures. In addition, they have such cardiovascular adaptations as an enlarged heart, enlarged and more numerous blood vessels, a fourfold increase in blood volume, and an increase in mitochondrial densities in their tissues. Oxygen is transported to the tissues dissolved in the blood plasma alone. But why would such an adaptation arise? Does the loss of red blood cells and hemoglobin confer an improved chance of survival? The answer to that question is probably not. Studies on red-blooded Notothenioids have shown that they can survive without using hemoglobin to transport oxygen. The random loss of the ability to produce hemoglobin, therefore, probably has no particular advantage or disadvantage in this unique environment.

In an age of global warming, icefish may be an evolutionary dead end. The complete loss of hemoglobin coding sequences means that there are no genes to modify and restore this function. As temperatures continue to rise in Antarctica, we may therefore se the extinction of these unique creatures.

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Period: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Surviving in Near-Freezing Water

1. How long ago was there a drastic change in the Antarctic water temperature?
2. Why were marine invertebrates able to withstand the temperature changes?
3. Did most fish fauna survive this drastic temperature change?
4. How many species of fish inhabit the seas around Antarctica?
5. What suborder do most of these fish belong to?
6. What is the first, and arguably most important adaptation that these fish have?
7. What molecule typically carries blood to the tissues (part of a red blood cell)?
8. What is an interesting characteristic of icefish – in regards to blood hemoglobin?
9. How is global warming threating icefish?