SPQ Module 12 – The Wonder of Anti-freeze Fish

It is early summer in Antarctica. Even so it was cold today - 44. The average annual temperature on the Polar Plateau is minus 50 C. Ray, Richard and Kevin plan to be outside in the cold for 35 days. Robert Scott and his team were outside for 150 days and ultimately froze to death.

Imagine if you had to go outside in this temperature and stay there for 35 days. Do you think you could survive?

Compared to many animals humans are not well prepared to manage extreme cold. We are furless and lose heat readily from our bodies. In order to survive in the cold, humans have developed strategies for keeping warm. These strategies fall into two main categories:

1. **Humans insulate themselves against the cold (clothing, sleeping bags, tents, houses, etc).**
2. **Humans burn sources of energy to generate heat (wood, oil, propane, etc).**

Often these strategies are used in combination. We insulate ourselves against the cold by building houses and trap heat in these houses by burning fuels like wood, oil and propane. When we are outside in the cold we wear insulating clothing and travel in heated vehicles.

There are some animals that insulate themselves from the cold; beavers build lodges, bears live in dens during the cold season, and mice take up residence in human dwellings. Yet most animals do not live in houses, or wear clothes – yet manage to survive and even flourish in extreme environments like Antarctica.

Penguins are remarkable for their ability to survive in the cold. They have developed behavioral and physiological adaptations that allow them to survive in the harshest environment in the world. Put yourself in the place of a penguin. You would spend your life standing on the edge of a glacier or ice floe with no clothing on, jumping periodically into the sub zero waters (because of the salt content in the ocean – the waters off Antarctica are often below zero). How do penguins stay warm?

figure 1: Emperor Penguin chick keeping warm (source: mtp@mtpa.org.uk)

Like all warm blooded animals – including human beings – penguins must maintain their core body temperature within a certain range. If their body temperature strays beyond this narrow range they will die. They maintain their body temperature by using a variety of strategies. Table 1 outlines these strategies.

In order to survive in a cold environment penguins have special short overlapping feathers and insulating fat stored under the skin. The classic rounded body shape decreases the surface to volume ratio of the penguin, thereby decreasing the contact surface of the penguin with the cold outside world and diminishing heat loss. They also have very small feet and wings (flippers) which further prevents heat loss. Penguins – like many birds – have special blood circulation arrangements whereby the blood flowing to the feet (arterial) is cooled by blood returning to the body (venous). This means less warmth is being transported to their feet where it can be lost, and more warmth is being transported to their body core where it can be maintained. What this means is that penguins' feet are much colder than the core of their body.

figure 2: Emperor Penguin in Adelie Land, Antarctica (source: Photo © Samuel Blanc)

In the deep of winter when it gets very cold penguins huddle together in groups and rotate from the outside of the group to the inside so that each penguin has a turn warming up in the middle of the group. It is principally the males that engage in this behavior because they are the ones that stay behind taking care of the eggs while the females go fishing. The males keep the eggs warm by incubating them on their feet under folds of skin & feathers.

TABLE 1: COMPARISON OF PENGUIN & HUMAN ADAPTATIONS FOR STAYING WARM

ADAPTATION	PENGUIN	HUMAN
OUTER INSULATION	Special short overlapping feathers.	No fur, no feathers.
INNER INSULATION	Fat storage under the skin.	No specially adapted fat storage.
BODY SHAPE	Rounded bodies which decreases surface to volume ratio and heat loss.	Body shape tends not to be rounded causing greater heat loss.
EXTREMITIES	Small feet and wings – decreasing heat loss through these extremities.	Long arms and legs.
BLOOD CIRCULATION	Special circulatory system to extremities.	No specially adapted circulatory system.
BEHAVIOR	Huddle together for warmth in a rotational manner.	Wear clothing; build shelters and burn fuel to stay warm.
INCUBATION OF YOUNG	Young are incubated in an external egg which the fathers hold on top of their feet and under folds of skin and feathers.	Young are incubated inside the mother's body.

Did You Know?

That fish in the Arctic Ocean also have an antifreeze protein that is similar but distinct from that of Antarctic fish. In other words fish at both ends of the planet evolved similar antifreeze survival strategies through completely different routes.

Penguins have adapted over many many years to be able to manage in the harsh Antarctic environment. These adaptations are thought to have developed (or been selected) gradually as the Antarctic Continental plate drifted south to a colder climate at the Pole. Similarly the fish living in the oceans around Antarctica have been naturally selected for living in the frigid waters of the Southern Ocean. In particular the Notothenioid fish, popularly known as Anti-freeze Fish, have developed a unique protein that prevents them from freezing when the water they live in goes below

zero (The freezing temperature of ocean water is minus 1.91 degrees because of the salt content).

figure 3: Antarctic toothfish (Notothenioidei, Nototheniidae) captured and photographed underwater in McMurdo Sound, Antarctica. This fish was approximately 100 lbs. (source: Photograph by Paul Cziko)

Normal fish bodily fluid freezes at about minus 1 degree Celsius. Anti-Freeze fish live in water that rarely rises above the freezing point of ocean water (-1.91 degrees) and is regularly filled with ice crystals. So why don't these fish freeze solid?

When an Anti-Freeze fish eats in the waters of Antarctica ice crystals routinely enter its stomach. These crystals would normally freeze the lining of the stomach and lead to the death of the fish. However Anti-Freeze fish secrete a protein called the Anti-Freeze Glycoprotein (AFGP) into their stomachs which plugs gaps in existing small ice crystals and prevents them from growing bigger. These anti-freeze proteins are also found in the fishes' blood streams. In other words Antarctic fish are able to survive with very small ice crystals in their bodies.

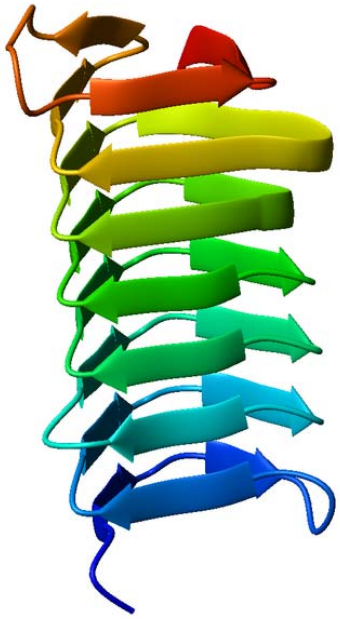

figure 4: Left-handed beta helix antifreeze protein (source: Wikimedia Commons)

There are 8 families of Antarctic notothenioids or anti-freeze fish, and five of them inhabit the Southern Ocean around Antarctica. These fish have been so successful that they make up about 90% of the biomass of the Southern Ocean. The thinking is that these fish adapted by the random occurrence of the anti-freeze protein (a random mutation) which offered them advantages in the cooling waters of the Antarctic continent as it moved south.

Ray, Richard & Kevin are using standard human techniques for keeping warm; wearing layers of clothing and sleeping in warm sleeping bags and a tent. Perhaps they don't need to resort to these techniques. Maybe one of them has a mutation that allows them to produce an antifreeze protein that will keep them alive should they get very cold. Perhaps for our next adventure they would be interested in taking a dip in the sub-zero Antarctic waters to see if ice crystals form in their blood!

Did You Know?

The Antarctic Toothfish, an antifreeze fish, has a heart that beats only once every 6 seconds, lives to fifty years of age and can weigh up to 300 lbs when full grown.

figure 5: Gilbert Kerr, bagpiper, with penguin. Photographed by William Speirs Bruce during the Scottish National Antarctic Expedition, 1902-04(source: First published in *The Voyage of the Scotia* by Rudmose Brown, Mossman and Pirie, Blackwoods, Edinburgh 1906)