PolarTREC Learning Resources

Details

Completion Time: About one period
Permission: Download, Share, and Remix

Frozen fish? Unique adaptations of Antarctic fish

Overview
Students will learn about adaptations that allow fish to survive the frigid waters of Antarctica and will make calculations to demonstrate how they survive these conditions.

Objectives
Students will determine how much antifreeze an Antarctic fish needs to lower the temperature of it's body fluids to -2.5°C. Students will develop an experimental procedure to conduct their tests and write up the procedures used.

Lesson Preparation
Background Information:
To survive living in frigid Antarctic waters some species of fishes, the Notothenioids, have developed proteins that act as antifreeze. These antifreeze proteins are a group of unique macromolecules that help some polar and subpolar marine bony fishes avoid freezing in their icy habitats.

Waters of the southern oceans are so cold that temperate and tropical fish would freeze if they were placed in this environment. The presence of salt in sea water allows it to remain liquid to about -1.9 °C. The antifreeze proteins, along with normal body salts, depress the freezing point of blood and body fluids to - 2.5 °C, slightly below the freezing point of sea water. These proteins bind to and inhibit growth of ice crystals within the body. The proteins attach to small ice crystals stemming their growth.

There may be several commercial applications of these antifreeze proteins. These compounds are about 300 times more effective in preventing freezing than conventional chemical antifreezes at the same concentrations. The effectiveness of fish antifreeze proteins in

Materials

- Ice
- Table or rock salt
- Antifreeze
- Beakers, graduated cylinders, etc.
- Thermometers

inhibiting ice growth suggests that they could be used to prevent freezing of food and freezing injury in several applications. The Food and Drug Administration has approved the use of the antifreeze proteins in 100 products and they have been added to ice cream and yogurt products. The addition of the proteins allows the production of very creamy, dense, reduced fat ice cream with fewer additives. The proteins used in food products are isolated from fish and replicated on a larger scale in yeast.

Ecology and Adaptations

Antarctica is a great place to study evolution. The continent's harsh environment has contributed to the evolution of an abundance of biological adaptations. Most marine fish living in temperate and tropical regions don't have antifreeze proteins and would freeze to death in Antarctic waters. The Notothenioids comprise about half of Antarctic marine fish species, but they account for 95% of all fish biomass in the region. How did these fish come to be the dominant fish species? Scientists believe that the dominance of these fish is a product of genetic and geological history.

Up until about 30 million years ago the waters around Antarctica were warmer than they are today because South America was connected to Antarctica allowing warm air from the north to flow into Antarctic waters. Fossil evidence indicates that the warmer waters permitted a greater diversity of marine fish species than there is today. The 90 or so Notothenioid species that inhabit Antarctica today did not exist then - only a single ancestral Notothenioid species is believed to have existed.

But sometime between 5 and 14 million years ago a chance mutation in the DNA of an ancestral Notothenioid created the gene that coded for the antifreeze protein. At the time of the mutation the ocean's waters were warmer than today and the gene had no impact on survival. Soon a shift in the earth's continental plates changed the shape of the Earth's land masses. Antarctica became an isolated continent ringed by a band of seas that created a powerful water current that prevented Antarctic waters from mixing with warmer seas. Over time the Antarctic seas grew much colder.

The Notothenioids that carried the gene for the antifreeze protein were able to survive in the cooling waters and the other species died out. Because Antarctic seas were mostly empty of fish they had little competition for food or habitats. Notothenioid subpopulations became adapted to different habitats eventually becoming unique enough to turn into new species. These adaptations resulted in an explosion of more than 90 new Notothenioid species that predominate in the Antarctic ecosystem today. This process is known as adaptive radiation.

Salt and Freezing Point Depression

Because of its effectiveness, availability, and low cost salt is the highway deicer in common use today. Salt is used as a deicer because it lowers the freezing point of water. The melting action of salt forms a brine, or a strong saline solution, that can penetrate below the surface of ice and packed snow. Brine prevents water from freezing and bonding to the pavement.

When ice melts due to the presence of salt heat is absorbed. This is called an endothermic reaction. The presence of a solute in water causes the freezing point to be lowered (freezing point depression) and the boiling point to be increased (boiling point elevation) by lowering the vapor pressure of the solution. The solution of salt in water has a lower vapor pressure than the ice so the ice changes its phase to liquid water. When salt is scattered on ice it is so soluble it immediately begins to dissolve in the moisture present on the surface of the ice, causing the ice to melt. The resulting brine dissolves more salt which in turn melts more ice and so on.

Procedure

Engage the students in a discussion about the unique adaptations of the Notothenioids. Point out to students that the same protein that keeps fish tissues from freezing is now being used in food products. Stress different aspects of the background material depending on course the lesson is used in.

Handout the student worksheet (attached). Explore the adaptation by having the students calculate the amount of antifreeze (in grams) needed to bring a volume of water to -2.5 °C (the body temperature of the fish). Depending on the level of the students provide instructions on how to do this, or let them come up with their own set up. They'll need an ice/salt bath (modeling the ocean - like used in making ice cream) to submerse a container ("the fish") in.

Students should put a known volume of water in a container immersed in the salt/ice bath, then gradually add known volumes of antifreeze until -2.5 °C is reached. Ice crystals will form if the solution is not stirred frequently. Once the correct temperature is reached have them "scale up" their results for a real fish.

Things they can assume ...

- A typical Notothenioid is the Antarctic Cod, the largest fish in Antarctic waters. The fish has an average mass of 25 kg and is found in the deep waters of the Ross Sea.
- Like us, the fish is approximately 70% water.
- The mass of one mL of water is 1 gm.
- The mass of one mL of antifreeze (Prestone LowTox brand) is 1.05 g. (adjust for whatever brand of antifreeze you use)

Sample Calculations:

A group of students determines that 20 mL of water is cooled to -2.5 °C by using 5 mL of antifreeze.

To scale this up for the fish ...

1. Keep in grams, so convert the 20 mL of water to 20 grams and convert the 5 mL of antifreeze to 5.25 grams.

2. The fish has a mass of 25 kg, and 70% of this is water, so the total mass of water in the fish is 17.5 kg or 17500 g.
3. Set up a ratio to solve for the amount of antifreeze the fish needs:
20 g water/5.25 g antifreeze = 17500 g water/# g antifreeze the fish needs
So, the fish needs 4594 g of antifreeze, but their antifreeze proteins are 300 times more effective than commercial antifreeze, so divide this number by 300. The answer for this group would be 15 g.

Run the experiment yourself ahead of time to determine the value for your antifreeze. Ideally don't tell the students how to set up the experiment or perform the calculations!! Have student groups share with the whole class how they set up their experiment and the results they got. Discuss reasons why results my have differed from group to group (inaccuracies in measurement, incorrect calculations, etc.).

Extension
Students in a biology class could further explore unique adaptations of species that live in Antarctica.

Another unique fish species, the ice fish, do not have red blood cells. The cold Antarctic water is so well oxygenated (colder water holds more dissolved oxygen than warmer water) that they don't need hemoglobin or myoglobin to carry oxygen to body tissues. They are called ice fish because they have clear blood and very pale body tissues.

Students in chemistry classes could do further work with freezing point depression and boiling point elevation – for instance researching the nature of the chemical mixture that is commonly spread on icy roadways instead of salt.

Younger students could make Ziploc bag ice cream (Place ice and salt in a large Ziploc bag and then put a smaller sandwich bag with milk, vanilla, and sugar in the big bag and shake until frozen.)

Resources
www.exploratorium.edu/origins/antarctica/ideas/fish.html
en. wikipedia.orglwikii Antifeeze_protein
www.nsf.gov/pubs/1996/nstc96rp/sb3.htm
www.saltinstitute.orgl42g.html

Assessment
N/A

Credits
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National Science Education Standards (NSES):

Content Standards, Grades 9-12

Content Standard A: Science As Inquiry
a. Abilities necessary to do scientific inquiry
b. Understandings about scientific inquiry

Content Standard C: Life Science
a. The cell
c. Biological evolution

Content Standard E: Science and Technology
b. Understandings about science and technology

Content Standard F: Science In Personal and Social Perspectives
f. Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science
a. Science as a human endeavor
b. Nature of scientific knowledge

Student Handout

Frozen Fish? A lab activity exploring a unique adaptation of Antarctic fish

Task - Determine how much antifreeze (in grams) an Antarctic fish needs to lower the temperature of its body fluids to -2.5 dc.

What should you do - Develop an experimental procedure to conduct your tests, conduct your tests, modify as necessary, and write up your results.

How should you do it - That's up to you. Be sure you keep records of everything you do.

Things you can assume:

- The fish in question is the Antarctic Cod, the largest fish in Antarctic waters. The fish has an average mass of 25 kg and is found in the deep waters of the Ross Sea.
- Like us, the fish is approximately 70% water.
- The mass of one mL of water is 1 g.
- The mass of one mL of antifeeze (Preston LowTox brand) is 1.05 g.

What should you turn in - Procedure, data, and calculations neatly presented on notebook paper or typed.