Title	Extremophiles! Life in Ice.
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Summary	Students discuss adaptations of life in extreme environments, with a particular focus on life in the Arctic. They will also examine sea ice as a habitable environment during a quick hands-on activity.
Grade Level	This was developed for a high school classroom (10-11 grade) but realistically, it can be adapted for any age
Time	Two 55 minute class periods with prep time (~20 minutes) required to make salt solutions and ice cubes. The prep should be done a few days in advance to allow salt water ice cubes time to freeze.
Objectives	1. Students will know that an extremophile is an organism that thrives in and may even require physically or geochemically extreme conditions that are detrimental to the majority of life on Earth. 2. Students will know that scientists study extremophiles to give them more information about the beginning of life on Earth, the limits of life, and the possibility of discovering life elsewhere in the solar system. 3. Students will know that salt water ice provides a habitat whereas fresh water ice does not. 4. Students will know that the organisms that live in salt water ice are integral parts of polar food webs.
Lesson Format	Discussion, Hands-on activity, Lecture
National Standards Addressed	9-12 Content Standard B: Science as Inquiry 9-12 Content Standard C: Physical Science: Structure and properties of matter K-4 Content Standard D: Life Science: Characteristics of organisms K-4 Content Standard D: Life Science: Organisms and environments 5-8 Content Standard D: Life Science: Populations and ecosystems 5-8 Content Standard D: Life Science: Diversity and adaptations of organisms 9-12 Content Standard D: Earth and Space Science: Biological evolution 9-12 Content Standard D: Life Science: Interdependence of organisms K-4 Content Standard G: Science in Personal and Social Perspectives: Changes in environments 5-8 Content Standard G: Science in Personal and Social Perspectives: Populations, resources, and environments

Materials:

1. Ice cubes trays
2. Plastic plates or Petri dishes
3. Food coloring (one small bottle per group)
4. Dixie cups
5. Salt
6. Water (potable and unpotable)
7. 1 set of color copies of Extreme Environments information sheets laminated or in protective covers, if possible (extreme environments.pdf)
8. Copies of Ice Observations worksheets for each student (Ice Observations.pdf)

Directions:

Preparation:

1. Because of the rate at which saltwater freezes at normal freezer temperatures, some advance preparation is necessary. Students will examine which ice type, sea ice or glacial ice, is a better habitat. Therefore, both types of ice cubes must be available to them for comparison/observation.
2. Begin freezing the saltwater cubes at least one day in advance. Students are placed in groups of two or four. Each group requires at least one set of cubes (salt and fresh water). Preparation steps:
    a. Mix a saltwater solution with the same salinity of ocean water. Use 34.1 g of salt per liter of water (68.2 g/2L) for a salinity of 33 ppt. Use this solution to make saltwater ice cubes.
    b. Make freshwater ice cubes using water from the tap.
3. (Optional) Have the students do a "Salinity Taste Test" to increase their understanding of the brine salinity that microbes deal with in sea ice. To do this you need potable water, salt and Dixie cups. Make 3 taste testing solutions:
    a. Fresh water (straight potable water)
    b. Seawater salinity (~33 ppt; add 34.1 g of salt per liter of water)
    c. Brine salinity – bottom of sea ice (~60 ppt; add 63.8 g of salt per liter of water)
    d. Brine salinity – top horizons of sea ice (~200 ppt (it can get saltier than this too!); add 250 g of salt per liter of water)
    e. Color code a set of Dixie cups for each class so that each student gets one of each type of solution. Make sure you make enough of each solution to fill a quarter of a Dixie cut **for each** student. Estimate: **Two liters is ample for a class of 30 students.**

Introduction:

Background: *Before this lesson, have students (and you) read the document, Life in Extreme Environments.pdf. Students should complete the accompanying questions, extremophile questions.doc, to ensure that they understand the concepts that will be examined during the lab.*

1. **Warm-up** (20 min) – Place students in groups. Give each group pictures of extreme environments (extreme environments.pdf). Ask students to **brainstorm the adaptations organisms would need to survive and thrive in extreme environments**. Students will list**,** draw**,** or describe those adaptations. Share with the class.
    a. The pictures are at the beginning of the PowerPoint document, extremophiles.ppt, and should be used as the class discusses each environment.

2. **Introduce today's topic of life at the polar regions**:
    a. "Think. Pair. Share." (10–15 min) – *Why is it important for us to understand how organisms are adapted to the conditions of the poles?* Have students think about this question, discuss it with a partner.
    b. Class discussion

3. **Content Introduction** (objectives 2, 3 and 4): Use provided PowerPoint, extremophiles.ppt and associated videos, to give students additional background on extremophiles. Identify why it is important to study them, and care about those in polar regions. **Prompt students** to take effective notes (15 - 20 min)
    a. Stop lecture at slide 17 to transition to ice activity and salinity taste test

Activity:

4. **Ice activity** (25 min): Initial observations**:** "What I see, What it means"
    a. In this activity, provide students with one fresh water ice cube and one salt water ice cube and food coloring.
        i. Explain to the students that are **going to investigate the identity of each type of ice (salt/sea or fresh/glacial) and to decide which type would be a better habitat for life**. To do this, they will**:**
            1. Observe the ice cubes
            2. Sketch and write down observations of the physical characteristics of the ice.
            3. Fill in "What I See" and "What this Means" worksheet (page 1, Ice Observations.doc).

ii. After recording their initial observations, students add a couple drops of food coloring to the ice. etch and record observations in the provided places. The presence of food coloring will help students SEE that saltwater ice has an abundance of pores and channels, which are perfect places for tiny organisms to live. In contrast, freshwater ice does not. Students can determine this because the food coloring slides off of the freshwater ice cubes.

5. **Salinity Taste Test** (10 minutes): If time permits, have students do the salinity taste test part of lesson.
   a. This brief activity gives students the opportunity to observe another challenge, aside from survival at sub-zero temperatures, faced by psychrophiles in ice: surviving in water with very high salt concentrations.

      Background for the teacher:

      The liquid brine in sea ice gets saltier the closer it gets to the ice-air interface. This occurs because the air above the ice, throughout the late fall, winter and much of spring, is often colder than the seawater below the ice. Therefore, the ice horizons closer to the air are colder than those closer to the water, allowing more of the water to freeze. In order to freeze, seawater needs to get "rid" of the salt so it can form pure ice crystals. As a result, the salt is further relegated to the brine pores and channels that exist in sea ice. Because more of the liquid water has frozen**,** cold ice has smaller AND fewer brine channels and pores than warmer ice. Therefore, colder ice has less, but saltier, brine, and warmer ice has more, but less salty, brine.

      i. **For the taste test:** Have students taste solutions with salinities of fresh water, ocean water, brine from lower ice horizons, and brine from upper ice horizons. Recipes for these solutions are provided above, in *Preparation*. A worksheet for this activity is provided on the second page of the Ice Observations.doc.

6. **Biological content (20 min)**
   a. Wrap up ice activity. Have students share what they observed.
   b. Wrap up salinity taste test activity: Ask students to share the water type/solution number pairings they came up with and their reasoning for their decisions. Discuss why different horizons in sea ice have different brine salinities. Discuss the differences and how they are relevant to the experiences of the lab. Slide 20 of extremophiles_forclassroom.pdf can help with this. Let the students know that even within a single meter of ice, organisms inhabiting that ice face widely different physical conditions**,** depending upon where they live in the ice.

c. ***Finish PowerPoint (extremophiles_forclassroom.ppt), beginning at slide 21***. The latter half of the PowerPoint focuses on the life in and around sea ice.
    i. The purpose of the last half of PowerPoint is to demonstrate the importance of extremophiles in a polar food web and to discuss some of their adaptations. Many of the organisms described at the end of the PowerPoint are not *extremophiles* per say but some of their adaptations to the environment are very unique and are required for survival in harsh polar environments.
d. Wrap up with in-class discussion on affects of climate change on the Arctic marine food web:
    i. Summarize the role that life in ice plays in the Arctic marine food web
    ii. It is predicted that the Arctic will be ice-free during summers as few as 30 years. How do you think the polar marine food webs will be affected? How might humans be affected by this decrease in ice?
        1. The last slide of extremophiles_forclassroom.pdf is an illustration from the Seattle Times depicted predicted changes in the Bering Sea ecosystem, a sub-Arctic sea, with climate change. This image would be useful to facilitate discussion.

Assessments:

- Reading questions
- Ice activity worksheet
- Salinity taste test worksheet

Vocabulary: most definitions courtesy of wikipedia

- Adaptation – a characteristic which is especially important for an organism's survival
- Brine – water saturated or nearly saturated with salt
- Extremophiles – organisms that thrive in or may even require physically or geochemically extreme conditions that are detrimental to the majority of life on earth
- Habitable Environment – an environment suitable for life
- Ice horizon – A particular depth or layer in ice that has generally uniform physical characteristics (for example, if someone samples a core of sea ice at 25 cm, 45 cm and 65 cm, these would be three different ice horizons)
- Food Web – the eating relationships between species within an ecosystem or a particular living space
- Psychrophiles – extremophiles that are capable of growth and reproduction in cold temperatures

- Salinity – the saltiness or dissolved salt content of a body of water
- Halophiles – extremophiles that thrive in environments with very high concentrations of salt (high salinity)

See the table in the Life in Extreme Environments.pdf document for classifications/definitions of other types of extremophiles

Extensions:

Following this lesson, we launched into a lab where we examined another type of extremophile: Halophiles. This section of the extremophiles unit was introduced as a case study of the Great Salt Lake. The materials for this lab came from the Institute for Systems Biology (ISB)**:**
http://baliga.systemsbiology.net/outreach_discussion/halo_lesson/network_interactions.php The resources provided by the Baliga group at ISB are great and perfect for high school classrooms! There are eight lessons based on Ecological Networks and Halophilic bacteria created for a high school biology class on the website. We used only some of the parts of this curriculum (lessons 3-7) with great success.

If you plan to do the halophile lab, definitely do the salinity taste test part of our Extremophiles: Life in Ice! Lesson. This will provide the students the opportunity to begin thinking about the conditions that halophiles face. Mention during the salinity taste test that next they will be examining and actually *growing* another type of extremophile that thrives in these high salt concentrations. Hopefully this will connect the two lessons.

Online resources:

Extremophile information:

- Microbial life in Extreme Environments: http://serc.carleton.edu/microbelife/extreme/
- Astrobiology Web: Life in Extreme Environments: http://www.astrobiology.com/extreme.html
- Space Ref.com: Life in Extreme Environments: http://www.spaceref.com/news/viewnews.html?id=463
- The Virtual Museum of Bacteria: http://bacteriamuseum.org/cms/Evolution/extremophiles.html

Sea ice information:

- Arctic Theme Page: How does Arctic Sea Ice form and Decay: http://www.arctic.noaa.gov/essay_wadhams.html
- National Snow and Ice Data Center: All About Sea Ice http://nsidc.org/seaice/index.html

- Encyclopedia Britannica: Sea Ice: http://www.britannica.com/EBchecked/topic/939404/sea-ice/257553/Ice-salinity-temperature-and-ecological-interactions

Life in the Arctic Ocean and Sea ice:

- Woods Hole Oceanus: Life in the Arctic Ocean: http://www.whoi.edu/oceanus/viewArticle.do?id=2467
- Dive and Discover: Deeper Discovery ~ Polar Regions: http://www.divediscover.whoi.edu/polar/index.html
- Arctic Theme Page: Organisms that Thrive in Arctic Sea Ice: http://www.arctic.noaa.gov/essay_krembsdeming.html