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Arctic Ocean Exploration

Being Productive in the Arctic Ocean

Focus
Primary productivity and limiting factors

Grade Level
9-12 (Chemistry/Biology)

Focus Question
What factors limit primary productivity in the Arctic Ocean?

Learning Objectives
Students will be able to identify the three realms of the Arctic Ocean, and describe the relationships between these realms.

Students will be able to identify major factors that limit primary productivity in the Arctic Ocean, and will be able to describe how these factors exert limiting effects.

Given data on potentially limiting factors and primary productivity, students will be able to infer which factors are actually having a limiting effect.

Additional Information for Teachers of Deaf Students
In addition to the words listed as key words, the following words should be part of the vocabulary list.
Benthic
Pelagic
Zooplankton
Phytoplankton
Sympagic
Primary productivity
Continental shelf
Diatoms
Algae
Photosynthesis
Chemosynthesis
Primary production

The words listed as key words are integral to the unit and will be used in the first step of the Learning Procedure. They are really the material that will become the basis of the lesson. There are no formal signs in American Sign Language for any of these words and many are difficult to lip-read. Having the vocabulary list on the board as a reference during the lesson will be extremely helpful. In addition, Steps 3 and 4 in the procedures should be reversed so that a brief discussion occurs prior to handing out the data cards.

Materials
- ❒ Five sets of Sample Data Cards, one set of ten cards for each student group
- ❒ Blank "Data Summary Sheet" (copy master included in this activity)

Audio/Visual Materials
None

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Five groups

Maximum Number of Students
25

Key Words

Pelagic
Benthic
Sympagic
Zooplankton
Primary productivity
Phytoplankton
PAR
Chlorophyll a

Background Information

The Arctic Ocean is the smallest of the world's four ocean basins with a total area of about 5.4 million square miles or 14 million square kilometers (roughly 1.5 times the size of the United States), and is bordered by Greenland, Canada, Alaska, Norway, and Russia. The Arctic Ocean has the widest continental shelf of any ocean, extending 750 mi (1,210 km) from the coast of Siberia, but also has areas that are quite deep (the average depth is 12,000 ft (3,658 m) and the maximum depth is 17,850 ft (5,441 m). The Chukchi Sea provides a connection with the Pacific Ocean via the Bering Strait, but this connection is very narrow and shallow, so most water exchange is with the Atlantic Ocean via the Greenland Sea.

The floor of the Arctic Ocean is divided by three submarine ridges (Alpha Ridge, Lomonosov Ridge, and the Arctic Mid-Oceanic Ridge) one of which (the Lomonosov Ridge) creates a relatively isolated area known as the Canadian Basin. This area is particularly interesting to scientists because its isolation could mean that it contains unique life forms that are found nowhere else on Earth. But the Arctic Ocean is not easily explored; it is almost entirely covered with ice for eight months of the year, a drifting polar ice pack covers the central and western portions year-round, and sea temperature seldom rises above 0°C. Although the Arctic is still the world's least explored ocean, new expeditions are about to give us much greater knowledge of the mysteries of this polar frontier.

At this point, we know that there are at least three distinct biological communities in the Arctic Ocean. The Sea-Ice Realm includes plants and animals that live on, in, and just under the ice that floats on the Arctic Ocean's surface. Because only 50% of this ice melts in the summer, ice flows can exist for many years and can reach a thickness of more than six ft. (2 m). Sea ice is not usually solid like an ice cube, but is riddled with a network of tunnels, called brine channels, that range in size from microscopic (a few thousandths of a millimeter) to more than an inch in diameter. Diatoms and algae inhabit these channels and obtain energy from sunlight to produce biological material through photosynthesis. Bacteria, viruses, and fungi also inhabit the channels, and together with diatoms and algae provide an energy source (food) for flatworms, crustaceans, and other animals. This community of organisms is called sympagic, which means "ice-associated." Partial melting of sea ice during the summer months produces ponds on the ice surface that contain their own communities of organisms. Melting ice also releases organisms and nutrients that interact with the ocean water below the ice.

The Pelagic Realm includes organisms that live in the water column between the ocean surface and the bottom. Melting sea ice allows more light to enter the sea, and algae grow rapidly since the sun shines for 24 hours a day during the summer. Through photosynthesis, these algae provide energy for a variety of floating animals (zooplankton) that include crustaceans and jellyfishes. Zooplankton, in turn, are the energy source for larger pelagic animals including fishes, squids, seals, and whales.

When pelagic organisms die, they settle to the ocean bottom as detritus, and become the energy source for inhabitants of the Benthic Realm. Sponges, bivalves, crustaceans, polychaete worms, sea anemones, bryozoans, tunicates, and ascidians are common members of Arctic benthic communities. These animals provide energy for bottom-feeding fishes, whales, and seals.

Most of our knowledge about biological communities in the Arctic Ocean comes from studies on portions

of the Ocean near the continental shelves. Very little research has been done on the sea ice, pelagic, and benthic realms in the deepest parts of the Arctic Ocean. These areas are the focus of the Arctic Ocean Expedition.

This activity is focused on primary productivity in the Pelagic Realm. Primary productivity refers to the amount of organic matter (usually expressed as grams of carbon per square meter per day) produced by organisms that are able to manufacture food from simple inorganic substances using energy from sunlight (in the case of photosynthesis) or chemical reactions (in the case of chemosynthesis). As far as we know, primary productivity in the Arctic Ocean occurs only through photosynthesis, and most of that photosynthesis takes place in microscopic floating algae (phytoplankton). As general principles, we know that photosynthesis requires photosynthetic plants, light, carbon dioxide, water, and nutrients; and that the availability of plant material, light, and nutrients can all limit the amount of photosynthesis that occurs. But we do not know which of these factors limit primary production in the Arctic Ocean, or how much primary production actually occurs there.

Learning Procedure

1. Review the Background Information on the Arctic Ocean and its three known biological realms with your students. Emphasize that the three realms are coupled, and that photosynthesis by microscopic algae (phytoplankton) provides the energy for other organisms in these realms (i.e., the algae are the "base of the food chain"). You may want to mention that other marine systems (such as those in the vicinity of hydrothermal vents) are not dependent on photosynthesis for energy, but rely on chemosynthesis instead (see http://oceanexplorer.noaa.gov/explorations/02galapagos/galapagos.html and http://oveanexplorer.noaa.gov/explorations/02fire/welcome.html for lesson plans and background information on these systems). If necessary, review the basic concepts of photosynthesis. Be sure students understand that photosynthesis can be limited if one or more of the necessary components is in limited supply.

2. Tell students that they will be examining data on primary productivity and factors that may limit this production in the Arctic Ocean. 10 data sets will be examined, representing samples that might have been taken at 10 different times of the year. As each sample is examined, students will be asked to explain the results in terms of what factors seem to be limiting primary productivity.

3. Distribute the five sets of sample data cards to the student groups. One group should receive the "Ice Cover" cards, a second group should receive the "Chlorophyll a" cards, a third group should receive the "PAR" cards, a fourth group should receive the "Nitrate" cards, and the fifth group should receive the "Primary Productivity" cards. Each set should contain one card for each of the 10 "Sampling Days."

4. Briefly discuss the meaning of each set of cards:

"Ice Cover" cards describe the percent of the sea surface that is covered with ice.

"PAR" cards describe the amount of photosynthetically active radiation (i.e., sunlight that is useable for photosynthesis) available as a percentage of the maximum radiation that occurs during the year.

"Chlorophyll a" cards describe the amount of chlorophyll a (which is a measure of the amount of photosynthetically-capable plant material present) in the surface seawater.

"Nitrate" cards describe the amount of nitrogen-containing nutrients present.

"Primary Productivity" cards describe the amount of organic matter that has been produced through photosynthesis at the sea surface.

5. Have each group read their cards for Sample Day #1. List the readings on the Blank Data Summary Sheet. When each group has read their cards, discuss the results. Repeat this process for the remaining nine Sample Days. The first few Sample Days should give the students a feel for what levels of the various factors may limit primary production. Refer to the "Teacher's Master Data Summary" and use the following guide as needed to aid these discussions.

Sample Day #1: This is a fairly high rate of Primary Productivity. Students should note that there is no ice to block sunlight, and PAR is fairly high. The significance of Chlorophyll a and Nitrate concentrations will become apparent as other days are examined.

Sample Day #2: 50% of the sea surface is covered with ice, and this limits Primary Productivity to less than half the value on Sample Day #1, even though the PAR and Nitrate levels are actually higher, and there are only slightly fewer algae (as indicated by Chlorophyll a) than on Sample Day #1. Reduction of sunlight by sea ice can be a major limiting factor for primary productivity in the Arctic Ocean.

Sample Day #3: Primary Productivity again is much lower than on Sample Day #1. A combination of ice cover and reduced PAR (perhaps it was a cloudy day!) are probably responsible, since Nitrate and Chlorophyll a levels are similar to previous days.

Sample Day #4: Primary Productivity is lowest yet, and the obvious cause is the greatly- reduced level of Nitrate.

Sample Day #5: Everything seems favorable here, but Primary Productivity is low. Let the students speculate on the cause. They should notice that PAR is nearly 100% (i.e., close to maximum), and may wonder whether there is such a thing as too much light. In the Arctic Ocean, photosynthetic algae can be adapted to rather low light conditions, and it is possible for photosynthesis to be inhibited if these algae are exposed to too much light.

Sample Day #6: Low Primary Productivity again; students should have no problem figuring out that extensive ice cover is the likely cause.

Sample Day #7: Time for inferences! When would you expect ice to cover 100% of the sea surface? Winter, of course! So, PAR would be zero because night lasts 24 hours in the polar winter. We would expect Chlorophyll a and Primary Produc-tivity to be pretty close to zero as well.

Sample Day #8: Reviewing the preceding data sets, students should notice that Nitrate does not appear to limit Primary Productivity except when it is in very limited supply. Since Primary Productivity is relatively high, and there is 30% ice cover, students could reasonably infer that Nitrate is not limiting in this case, so it could be any of the previous levels except 0.2.

Sample Day #9: Low PAR is the key here. It is probably early winter, so students could conclude that ice cover is probably fairly high (above 70%) and Primary Productivity is probably quite low.

Sample Day #10: Since all other factors seem pretty favorable, yet Primary Productivity is low, students should suspect that Nitrate levels are low enough to be limiting.

6. Have students write individual summaries of factors that limit Primary Productivity in the Arctic Ocean.

The BRIDGE Connection

www.vims.edu/bridge/polar.html
www.vims.edu/bridge/plankton.html

The "Me" Connection

Have students write a short essay or prepare a brief oral presentation on how knowledge of Primary Productivity in the Arctic Ocean might benefit them personally, and/or why they think this knowledge is (or is not) important. Ask students to share their thoughts with the class.

Connections to Other Subjects

English/Language Arts, Mathematics

Evaluation

Have students write their own interpretations of Sample Days #6 – 10 before these are discussed as a group.

Extensions

1. Have students visit http://oceanexplorer.noaa.gov to keep up to date with the real-time exploration of the deep Arctic Ocean, and to find out what organisms researchers actually find in the three realms.

2. Have students research primary productivity in temperate and/or tropical ocean waters, and compare these data with primary productivity in the Arctic Ocean.

Resources

http://oceanexplorer.noaa.gov – Follow the Arctic Ocean Expedition daily as documentaries and discoveries are posted each day for your classroom use. A wealth of information can also be found at this site.

http://www.sciencegems.com/earth2.html – Science education resources

http://www-sci.lib.uci.edu/HSG/Ref.html – References on just about everything

http://photoscience.la.asu.edu/photosyn/education/learn.html – Links to many sites and activities about photosynthesis

Smith, Jr., W. O. 1995. Primary productivity and new production in the Northeast Water (Greenland) Polynya during summer 1992. Journal of Geophysical Research 100: 4357-4370. – The scientific journal article upon which this activity is based.

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science

- Chemical reactions

Content Standard C: Life Science

- Interdependence of Organisms

Content Standard D: Earth and Space Science

- Energy in the Earth system

For More Information

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http://oceanexplorer.noaa.gov

Student Handout

ICE COVER DATA

Sample Day #1

Ice Cover = 0%

ICE COVER DATA

Sample Day #2

Ice Cover = 50%

ICE COVER DATA

Sample Day #3

Ice Cover = 50%

ICE COVER DATA

Sample Day #4

Ice Cover = 10%

ICE COVER DATA

Sample Day #5

Ice Cover = 0%

ICE COVER DATA

Sample Day #6

Ice Cover = 70%

ICE COVER DATA

Sample Day #7

Ice Cover = 100%

ICE COVER DATA

Sample Day #8

Ice Cover = 30%

ICE COVER DATA

Sample Day #9

Ice Cover = GUESS!

ICE COVER DATA

Sample Day #10

Ice Cover = 15%

Student Handout

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #1

PAR = 75% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #2

PAR = 78% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #3

PAR = 45% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #4

PAR = 76% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #5

PAR = 98% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #6

PAR = 79% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #7

PAR = GUESS!

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #8

PAR = 82% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #9

PAR = 10% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #10

PAR = 79% of maximum

Student Handout

CHLOROPHYLL a DATA

Sample Day #1

Chlorophyll a = 87 µg/l

CHLOROPHYLL a DATA

Sample Day #2

Chlorophyll a = 76 µg/l

CHLOROPHYLL a DATA

Sample Day #3

Chlorophyll a = 73 µg/l

CHLOROPHYLL a DATA

Sample Day #4

Chlorophyll a = 82 µg/l

CHLOROPHYLL a DATA

Sample Day #5

Chlorophyll a = 85 µg/l

CHLOROPHYLL a DATA

Sample Day #6

Chlorophyll a = 71 µg/l

CHLOROPHYLL a DATA

Sample Day #7

Chlorophyll a = GUESS!

CHLOROPHYLL a DATA

Sample Day #8

Chlorophyll a = 76 µg/l

CHLOROPHYLL a DATA

Sample Day #9

Chlorophyll a = 5 µg/l

CHLOROPHYLL a DATA

Sample Day #10

Chlorophyll a = 73 µg/l

Student Handout

NITRATE DATA

Sample Day #1

Nitrate = 6.2 µmol/l

NITRATE DATA

Sample Day #2

Nitrate = 8.4 µmol/l

NITRATE DATA

Sample Day #3

Nitrate = 11.3 µmol/l

NITRATE DATA

Sample Day #4

Nitrate = 0.2 µmol/l

NITRATE DATA

Sample Day #5

Nitrate = 7.1 µmol/l

NITRATE DATA

Sample Day #6

Nitrate = 6.7 µmol/l

NITRATE DATA

Sample Day #7

Nitrate = 5.2 µmol/l

NITRATE DATA

Sample Day #8

Nitrate = GUESS!

NITRATE DATA

Sample Day #9

Nitrate = 7.6 µmol/l

NITRATE DATA

Sample Day #10

Nitrate = GUESS!

Student Handout

PRIMARY PRODUCTIVITY DATA

Sample Day #1

Surface Primary Productivity =
9.3 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #2

Surface Primary Productivity =
4.3 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #3

Surface Primary Productivity =
5.1 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #4

Surface Primary Productivity =
3.4 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #5

Surface Primary Productivity =
4.3 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #6

Surface Primary Productivity =
3.4 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #7

Surface Primary Productivity =
GUESS!

PRIMARY PRODUCTIVITY DATA

Sample Day #8

Surface Primary Productivity =
6.5 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #9

Surface Primary Productivity =
GUESS!

PRIMARY PRODUCTIVITY DATA

Sample Day #10

Surface Primary Productivity =
2.6 mg C/m^2/day

Student Handout

Teacher's Master Data Summary

Sample Day	Ice Cover (% of surface)	PAR* (% of maximum)	Chlorophyll a (µg/l)	Nitrate (µmol/l)	Primary Productivity (mg C/m²/day)
1	0	75	87	6.2	9.3
2	50	78	76	8.4	4.3
3	20	45	73	11.3	5.1
4	10	76	82	0.2	3.4
5	0	98	85	7.1	4.3
6	70	79	71	6.7	3.4
7	100	GUESS	GUESS	5.2	GUESS
8	30	82	76	GUESS	6.5
9	GUESS	10	5	7.6	GUESS
10	15	79	73	GUESS	2.6

* photosynthetically active radiation

Student Handout

DATA SUMMARY SHEET

Sample Day	Ice Cover (% of surface)	PAR* (% of maximum)	Chlorophyll a (µg/l)	Nitrate (µmol/l)	Primary Productivity (mg C/m²/day)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

* photosynthetically active radiation

DATA SUMMARY SHEET

Sample Day	Ice Cover (% of surface)	PAR* (% of maximum)	Chlorophyll a (µg/l)	Nitrate (µmol/l)	Primary Productivity (mg C/m²/day)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

* photosynthetically active radiation