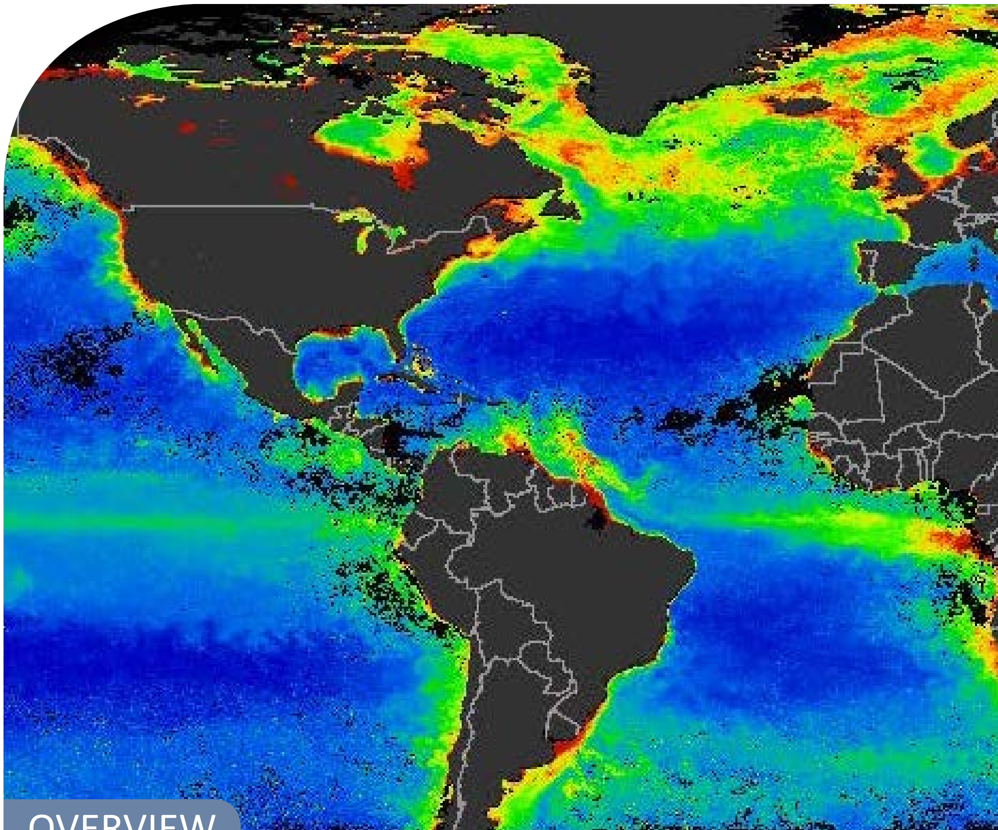
Ocean Productivity



ACTIVITY TIME

90 minutes

LEARNING OUTCOMES

- Explain how ice algae and spring blooms affect overall productivity.
- Compare and contrast the seasonal productivity of an open ocean in the arctic, a polynya and a warm-water ocean.
- Explain the technology that is used to study these habitats.
- Graph and analyze data from logarithmic scales.

OVERVIEW

Students compare ocean productivity in the Arctic Ocean, an open water polynya and a warm ocean, exploring the influence of sea ice on primary productivity (phytoplankton).

FLOW

1. Watch a video about phytoplankton in the oceans of the world
2. Review the importance and cyclical nature of phytoplankton in the Background section
3. Student activity: reading maps and graphing productivity of phytoplankton in three locations
4. Discuss results and complete Discussion Questions
5. Optional: a video about phytoplankton in the Amazon

CONTENTS

STUDENT OVERVIEW

WHY?

Phytoplankton are vital to the marine food web and the overall health of the planet. They are the biggest source of oxygen for earth's inhabitants as well as a primary indicator for climate change.

WHAT?

- The role of phytoplankton in supporting the food web
- Logarithmic scales determining the activity of phytoplankton
- The ways phytoplankton indicate climate change and other events affecting the oceans

HOW?

- Watch a video
- Review Background section
- Complete a graphing activity
- Share results among the class
- Discussion Questions
- (Optional) Video about phytoplankton in the Amazon

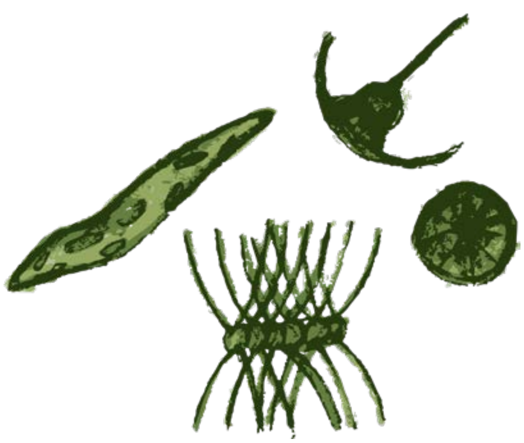


IMAGE 1 Phytoplankton (S. DesRoches)

BACKGROUND

In the oceans, the main primary **producers** are **algae** rather than the vascular plants we see on land. Since sunlight is required for photosynthesis, algae and seaweeds can grow only in shallow waters where sunlight can reach the ocean floor. Free-floating algae, however, can grow anywhere in the ocean, as long as they have access to sunlight, carbon dioxide, water, and required nutrients like nitrogen and phosphorus. In many marine systems these nutrients are the limiting factor, because they settle to the bottom, below the **photic zone**, or depths at which photosynthesis can occur. Consequently, oceans with strong upwelling (vertical movement in the water column) are some of the most productive areas because these nutrients are returned to sunlit surface waters. The polar oceans tend to have lots of upwelling and nutrients are brought up from the sediment at the ocean bottom, enriching the surface layer. However, for long periods of the year, sunlight is lacking. When the ocean is frozen, very little light can penetrate the snow and ice to the water below. Even in **polynyas**, which may remain ice-free all winter, photosynthesis cannot occur because there may be little or no light for months at a time.

Primary production in polar oceans tends to be very seasonal. There is almost no primary-producer growth for many months through the winter, and then rapid growth in the spring and early summer. In the

IMAGE 2 These unicellular algae can live in the lower part of sea ice during the winter. They grow within little channels in the sea ice called brine channels and are released into the water column with the melting of the sea ice in the spring. (NOAA)

VOCABULARY

Algae: Simple photosynthetic, autotrophic organisms; may be unicellular, colonial or multicellular.

Biomass: The mass of living organisms in an area, often an estimate.

Chlorophyll a: A green pigment found in the chloroplasts of plants and algae; functions in the conversion of solar energy to biochemical energy.

Consumer: An organism that obtains food by eating other organisms or their by-products.

Photic zone: The upper layer of the ocean, where sufficient light penetrates for photosynthesis to occur.

Phytoplankton: Plankton that are capable of photosynthesis.

Plankton bloom: A rapid increase in the numbers and density of plankton, usually algae.

Polynya: An area of open water surrounded by sea ice; often remains open throughout the winter.

Primary production: The production of organic compounds from carbon dioxide, mainly by photosynthesis.

Producer: An autotroph, usually photosynthetic; collectively, producers form the trophic level that supports all other levels.

Proxy: In ecology a measurement used as an indicator for something else.

Spring bloom: A sudden and strong bloom of phytoplankton that usually occurs in temperate and subpolar waters.

Arctic Ocean, there are generally two main pulses of primary production each year. The first occurs when the snow and ice begin to melt. Especially adapted ice algae, which are able to photosynthesize at very low light levels and temperatures, begin growing quite early in the spring when most of the ocean is still covered by sea ice. Over the course of the winter, these algal cells and nutrients, which were trapped in the ice when it froze, slowly migrate down through the ice to the lower surface. This is where the ice algae grow in the spring, providing an important early food source for primary **consumer**s in Arctic sea ice ecosystems.

The second pulse of growth occurs in early summer, as the ice melts further and starts to break up. In the open water, the spring **plankton bloom** of **phytoplankton** (floating algae and other autotrophs) begins. Polynyas, which remained ice-free all winter, provide areas where the **spring bloom** can get a 'head start' as soon as sunlight is sufficient to support photosynthesis. With abundant nutrients and long hours of daylight, phytoplankton growth is extremely rapid in the short polar summer.

Marine primary producers are amazingly efficient. They are responsible for almost half of total global primary productivity yet make up only 0.2% of the **biomass**. As all other organisms in an ecosystem depend on the ability of primary producers to convert light into food, measuring primary productivity in the oceans can tell us a lot, not only about the photosynthesizing algae, but also about the distribution of marine life in general. In this activity, students will use maps of global marine primary production to create graphs that illustrate the annual fluctuations in primary productivity in different parts of the oceans.

Marine primary production is estimated from satellite images that measure the concentration of **chlorophyll a** in surface waters. The level of chlorophyll a is used as a **proxy** to indicate how much photosynthetic activity is occurring. Tropical ecosystems tend to have a fairly constant and comparatively low rate of photosynthesis. This is because there is a little upwelling and nutrients from deep waters rarely mix with the very warm surface waters. This differs from the nutrient-rich waters of arctic ecosystems where upwelling is common.

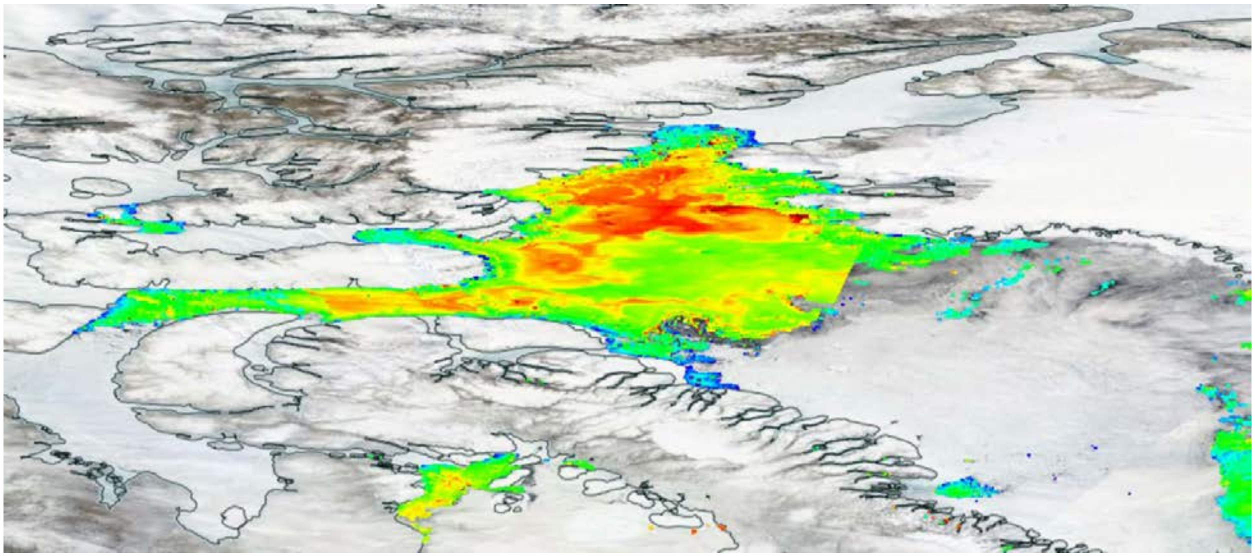


IMAGE 3 A close up visualization of the primary productivity, as measured using a logarithmic scale, of the Northwater Polynya and Lancaster Sound on June 14, 2016. (D.Fuglestad[1])

PREPARATION

MATERIALS

- Computers with internet access
- Rulers and pencils OR computers with Excel or another graphing program

RESOURCES

NASA phytoplankton video
5 minute video, with good visuals, which describes the importance of phytoplankton
https://arcticeider.com/links/ocp07

Monthly Ocean Chlorophyll Concentrations
Maps showing the chlorophyll concentration of the earth's oceans on a monthly basis over the course of a year. Student use this in the main activity. It is included in the teacher guide and more copies can be printed from this link.
https://arcticeider.com/links/ocp09

SET-UP

1. Display the Monthly Ocean Chlorophyll Concentrations on the projector for the class to see or print a copy for each student.
2. Load the NASA phytoplankton video.

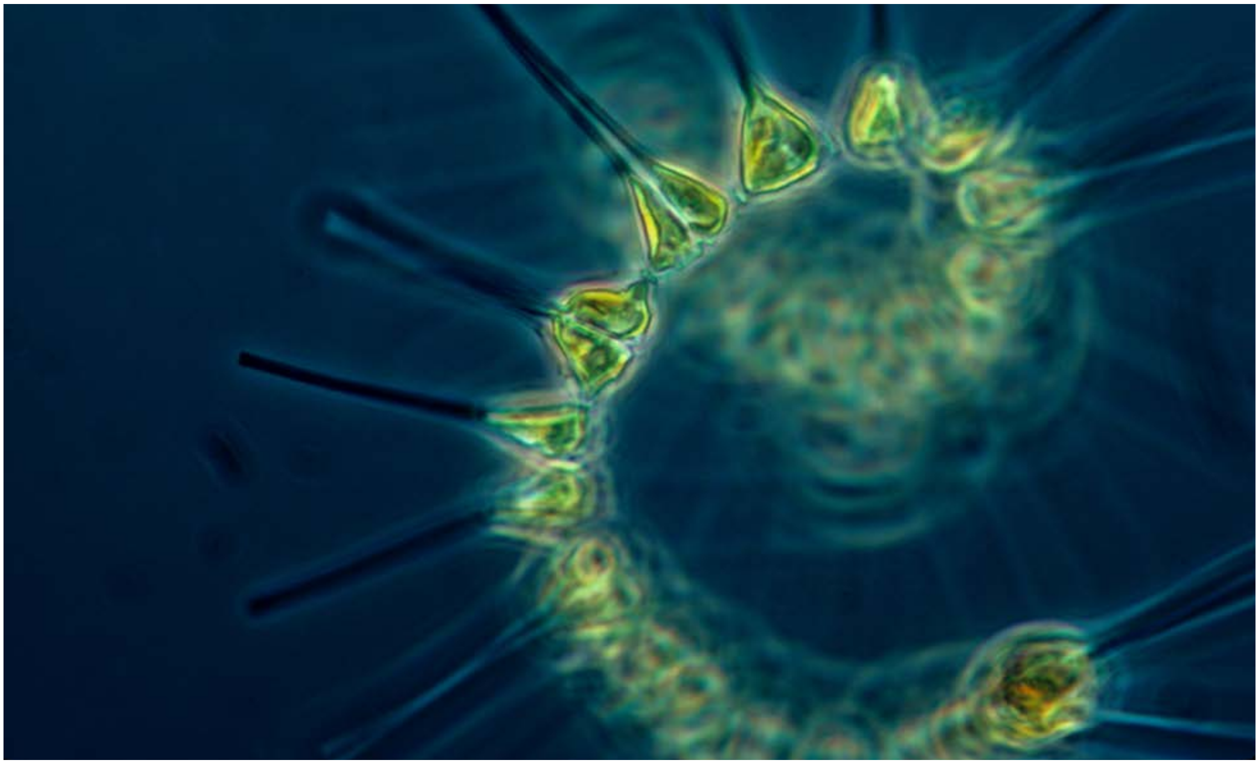


IMAGE 4 Phytoplankton - the foundation of the oceanic food chain. (NOAA MESA Project[2])

PROCEDURE

1. Watch the NASA phytoplankton video (pg. 5).
2. Review the information from the Background (pg. 3).
3. Split the class into groups of three. Each student in a group will focus on a different kind of marine environment:

   A The Arctic Ocean

   B An arctic polynya

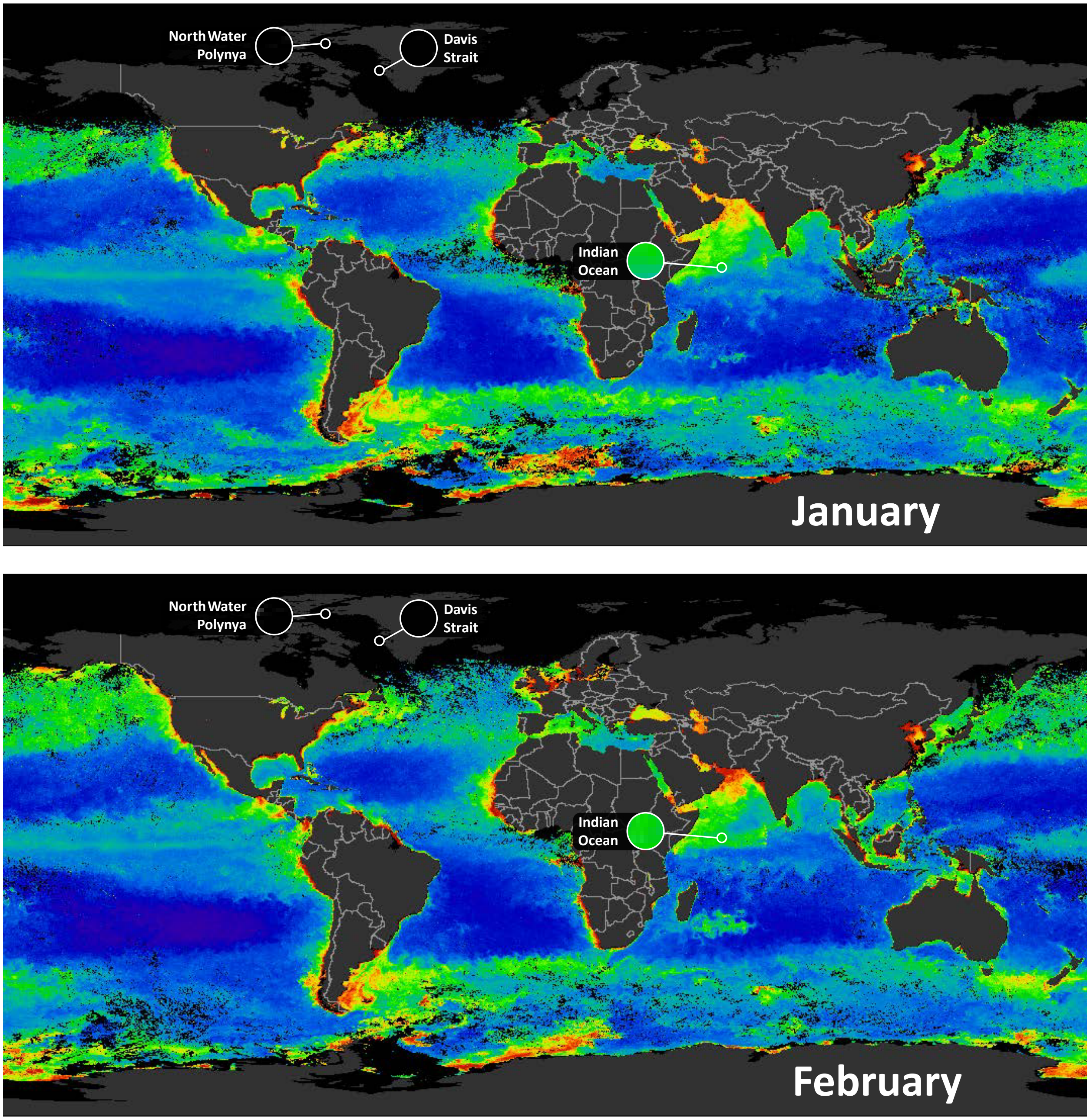
   C Tropical ocean

4. Use the Monthly Ocean Chlorophyll Concentration Maps (pg. 7) to determine primary productivity in each region over the course of one year. The maps can be displayed on a Smart Board or printed out. Three locations have been marked on the maps.

   The colour legend on these maps uses a logarithmic (log) scale to visualize the concentration of chlorophyll a in surface waters. Log scales are useful for working with a large range of values and make data analysis easier. Students can estimate the value for each month based on the colour present in their chosen area. You can watch the Khan Academy Logarithmic Scale (pg. 16) video to learn more about this.

5. Students record their own data in *Table 1*.
6. Each student should graph the data by hand on *Figure 2* or use a computer-graphing program. Months of the year go on the x-axis, and mg/m^3 of Chlorophyll a on the y-axis.
7. Have each student share with their groups members how the trends on their graph are caused by ocean conditions.
8. Come back together as a class. Put three graphs, one from each region, up on the board. Compare and contrast each graph as a class. Why are they different? What causes primary productivity to be so different between tropical and Arctic marine environments? What is different about photosynthesis in a polynya?
9. Solidify understanding with the discussion questions.
10. (Optional) Watch the Earth System 5 - Phytoplankton (pg. 16) video, demonstrating phytoplankton growth in the Amazon from ocean nutrient sources, and from Sahara desert sandstorms.

MONTHLY OCEAN CHLOROPHYLL CONCENTRATION MAPS



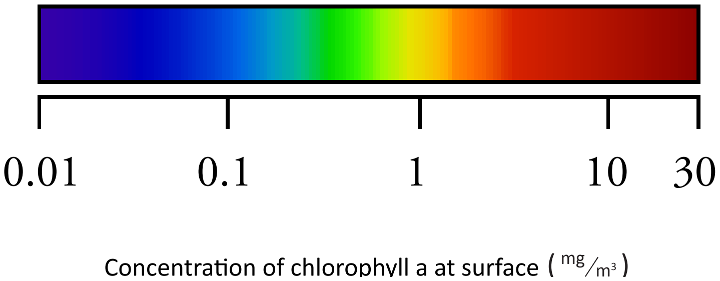
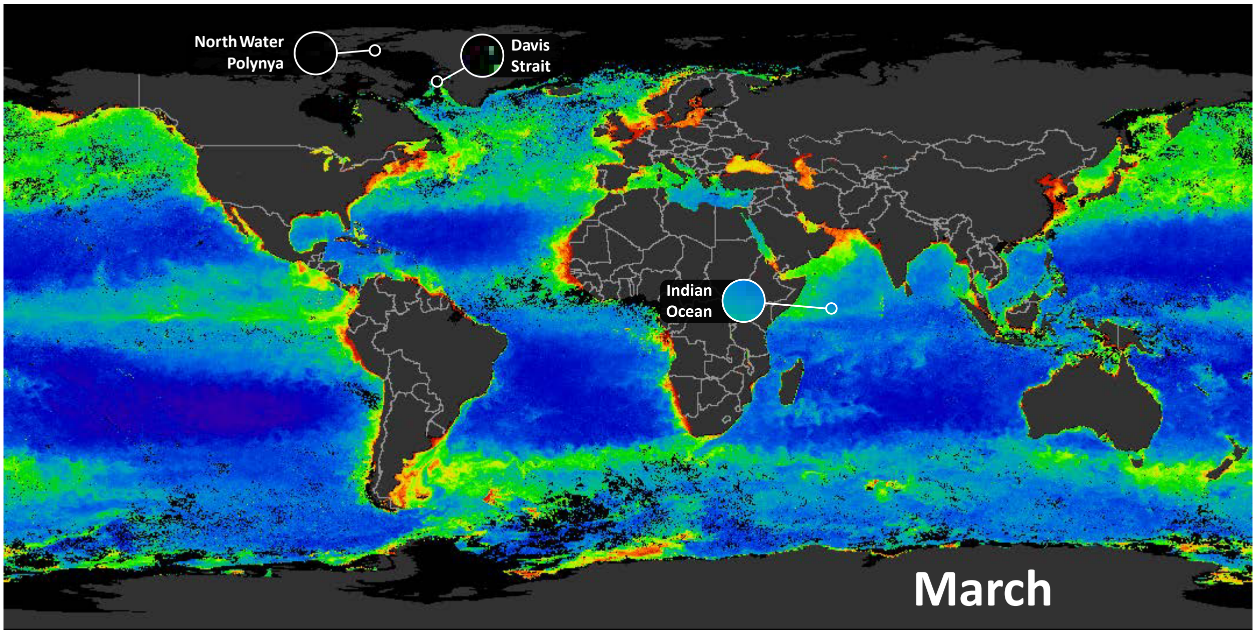
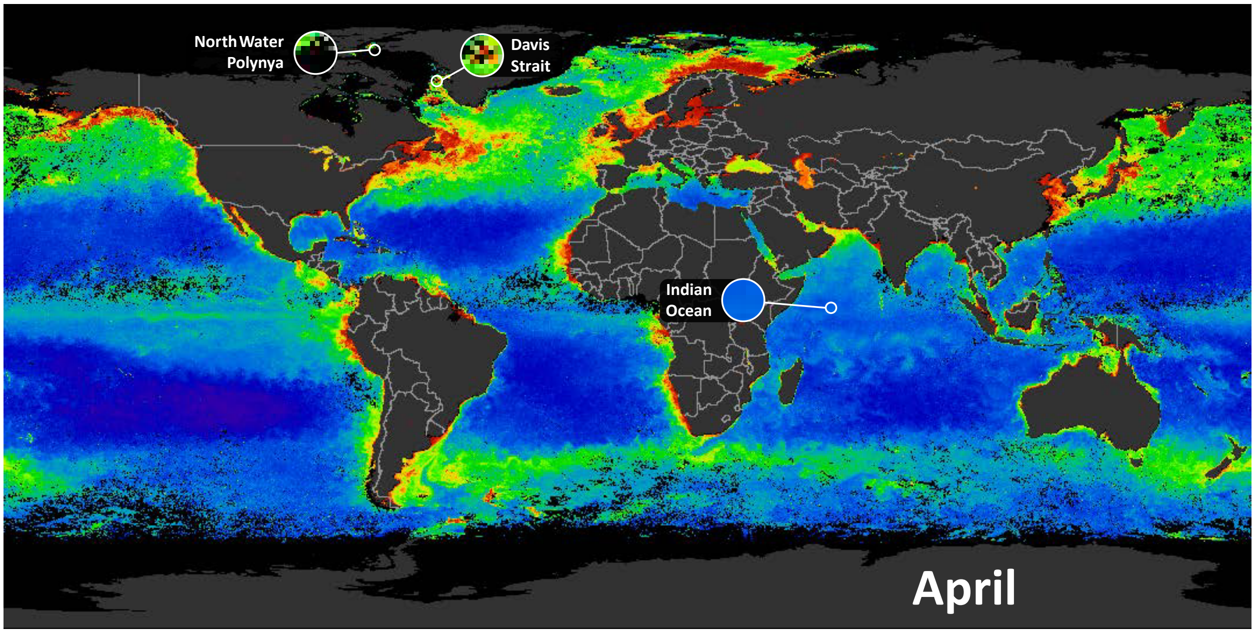
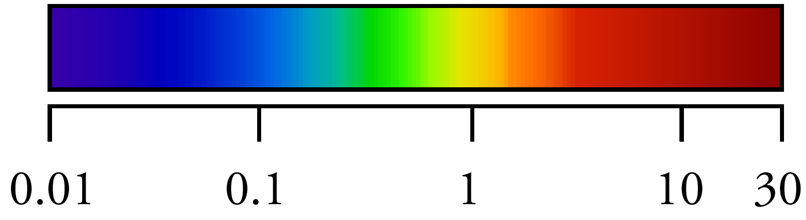


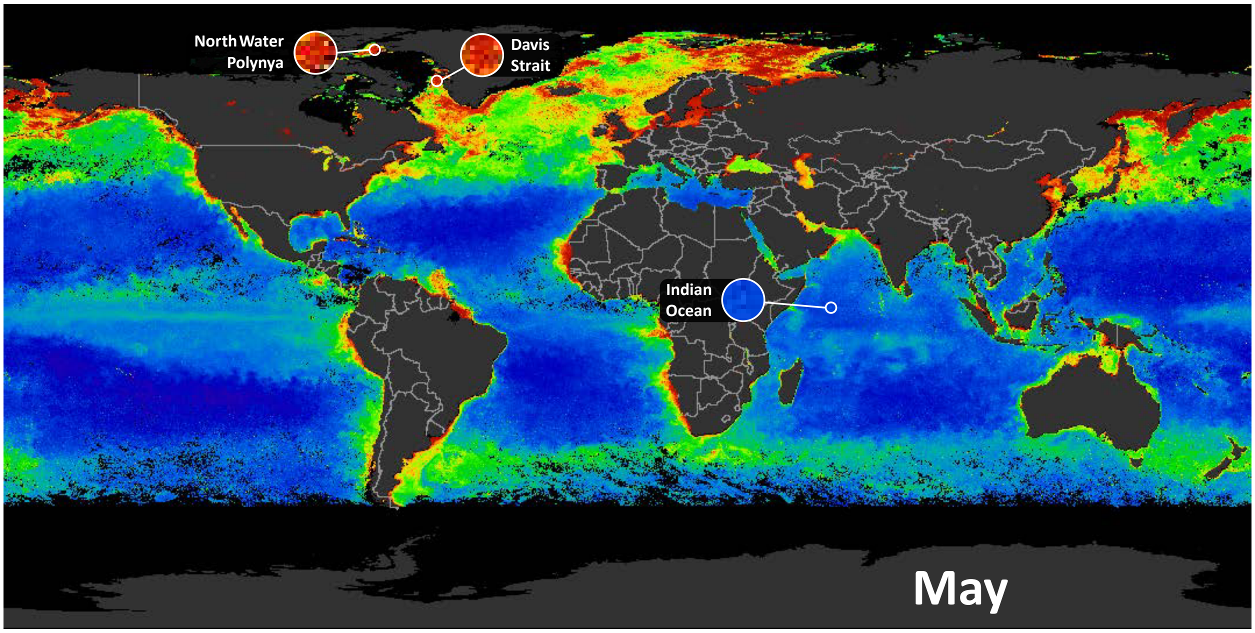
FIGURE 1 Logarithmic scales, like the log scale used here to visualize the concentration of chlorophyll a in surface waters, are useful for working with a large range of values.

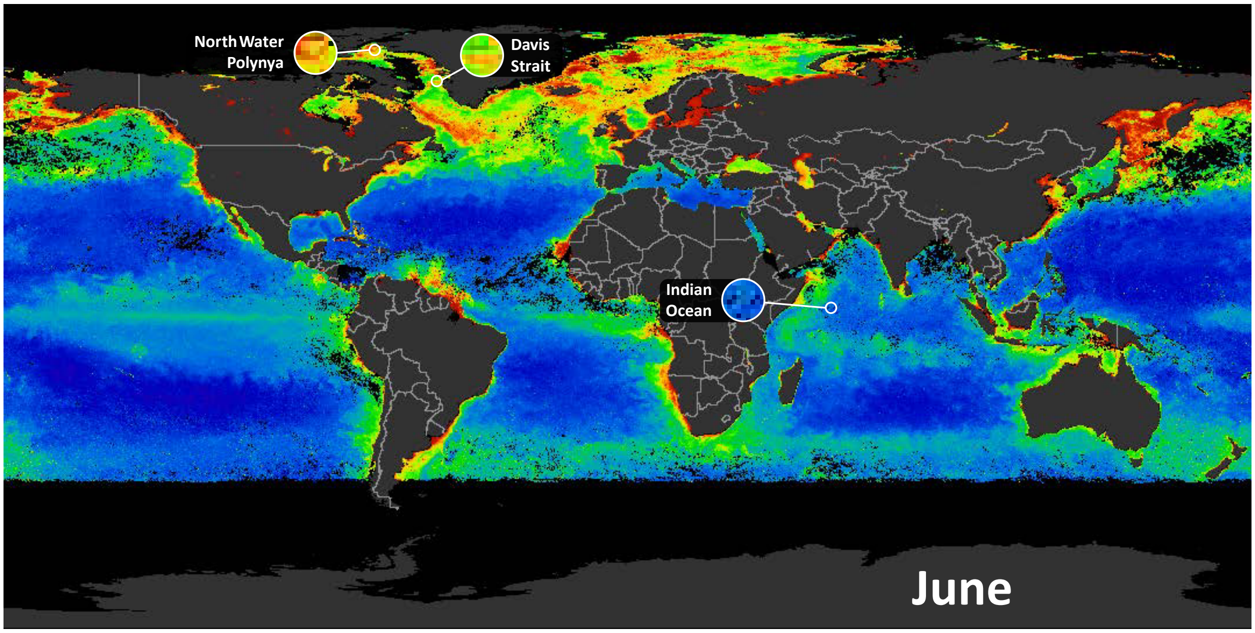


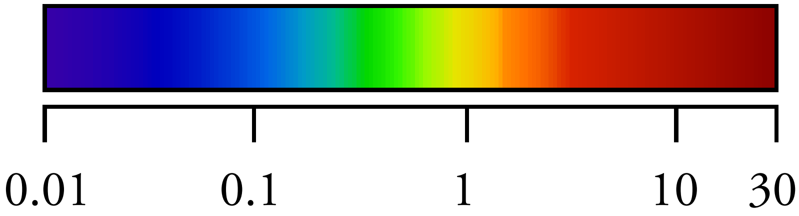




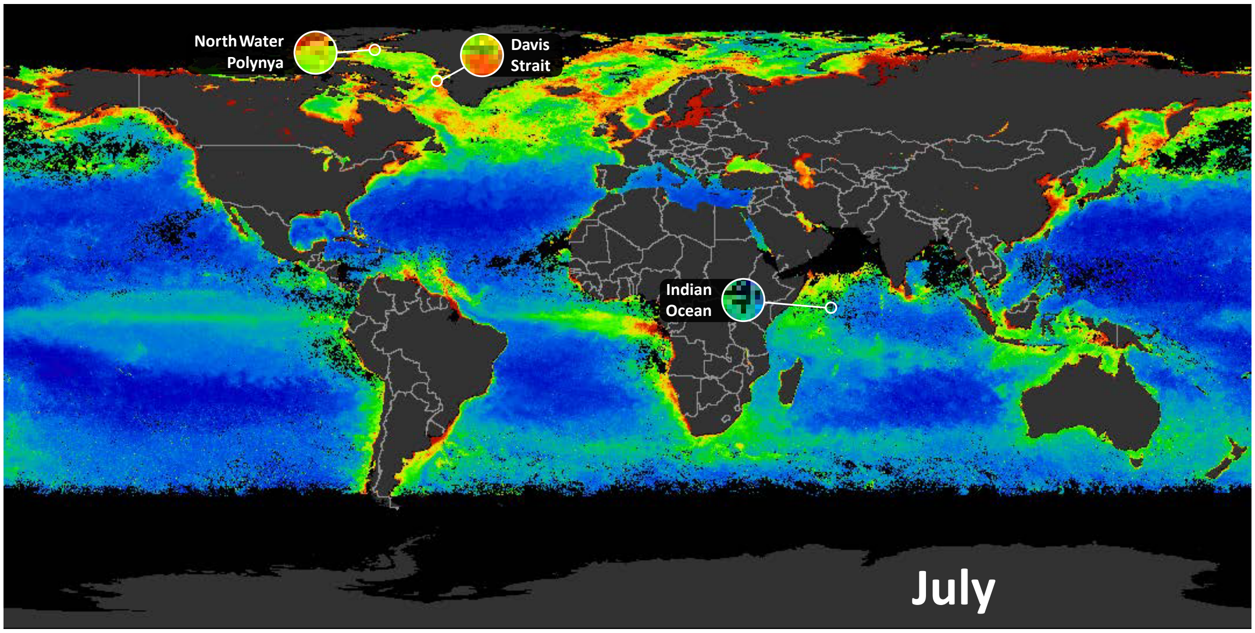
Concentration of chlorophyll a at surface ($^{mg}/_{m^3}$)

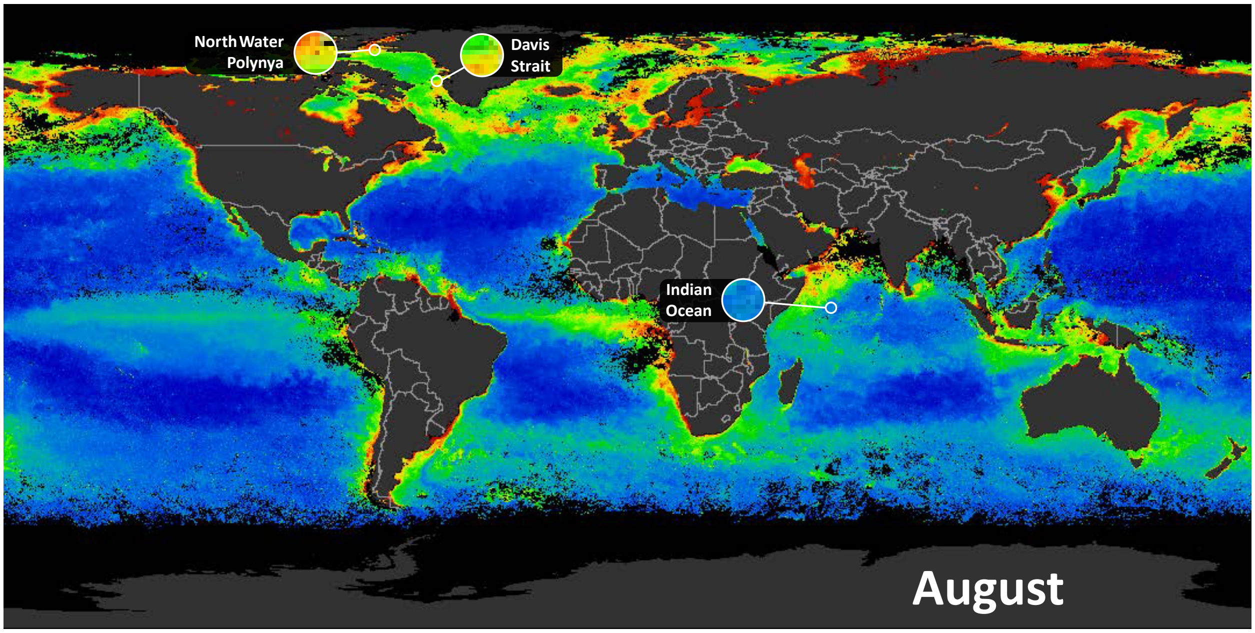


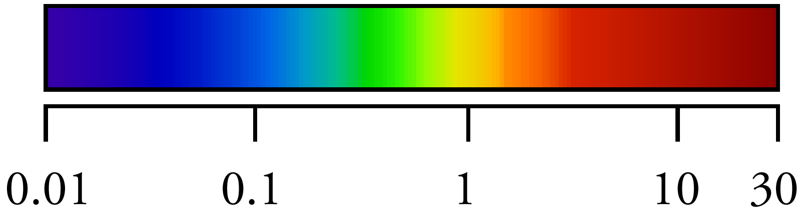




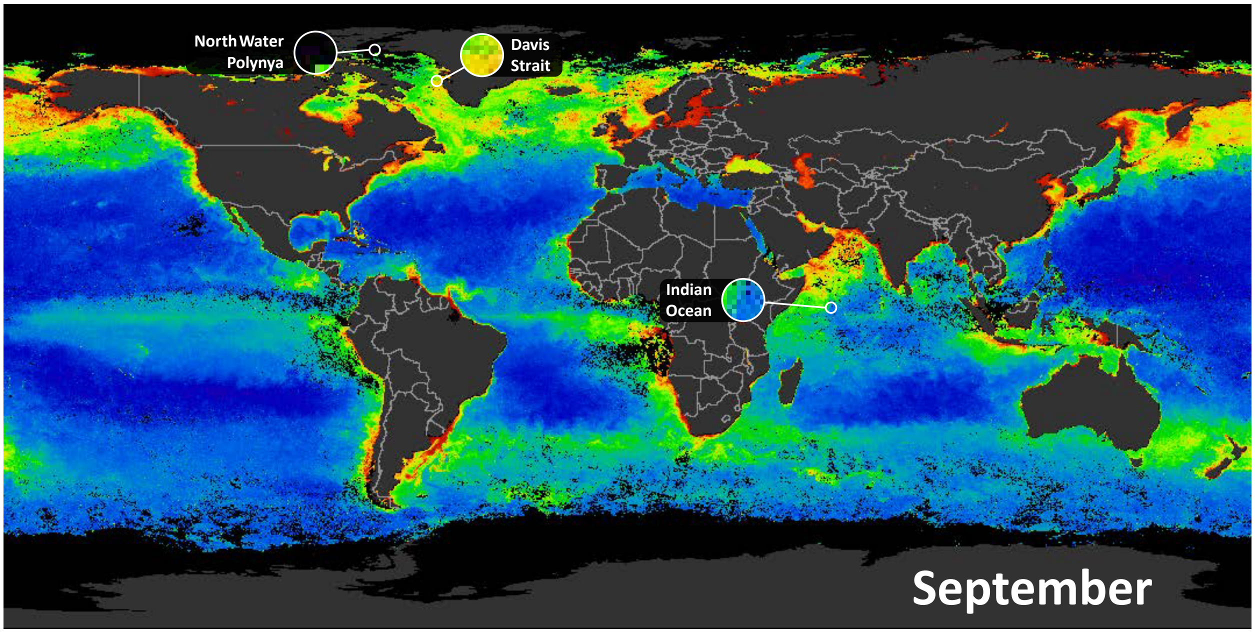
Concentration of chlorophyll a at surface (mg/m³)

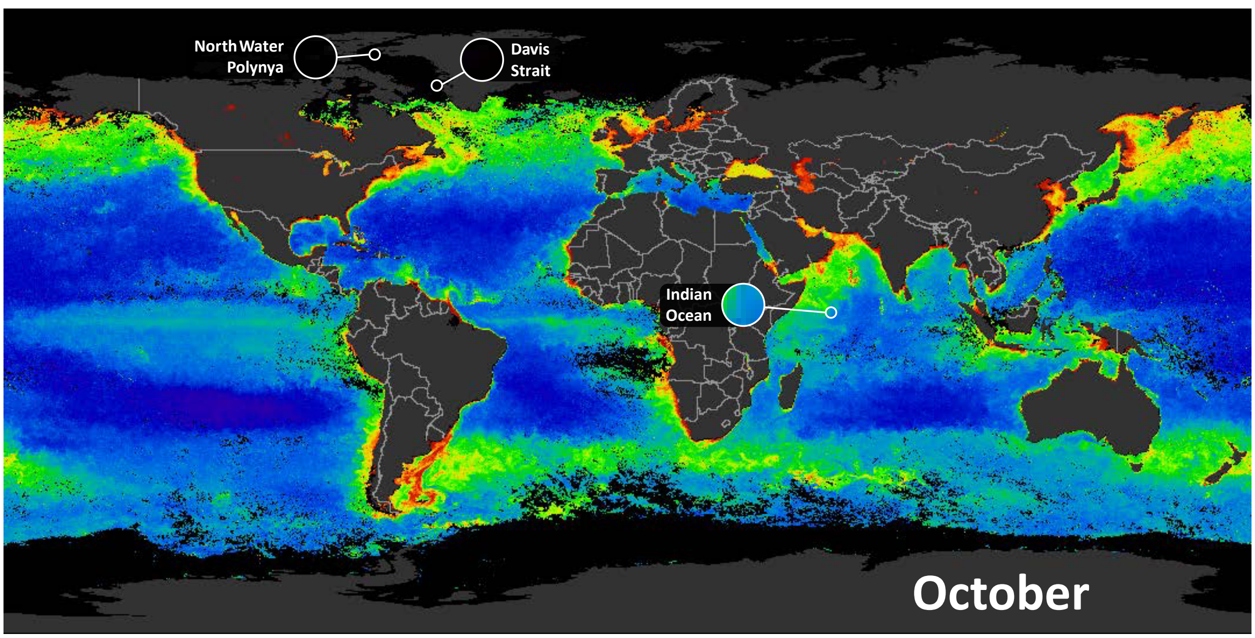


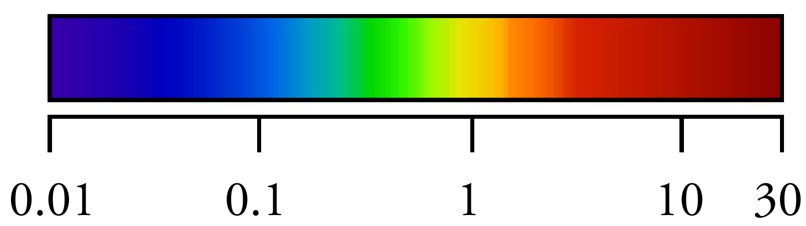




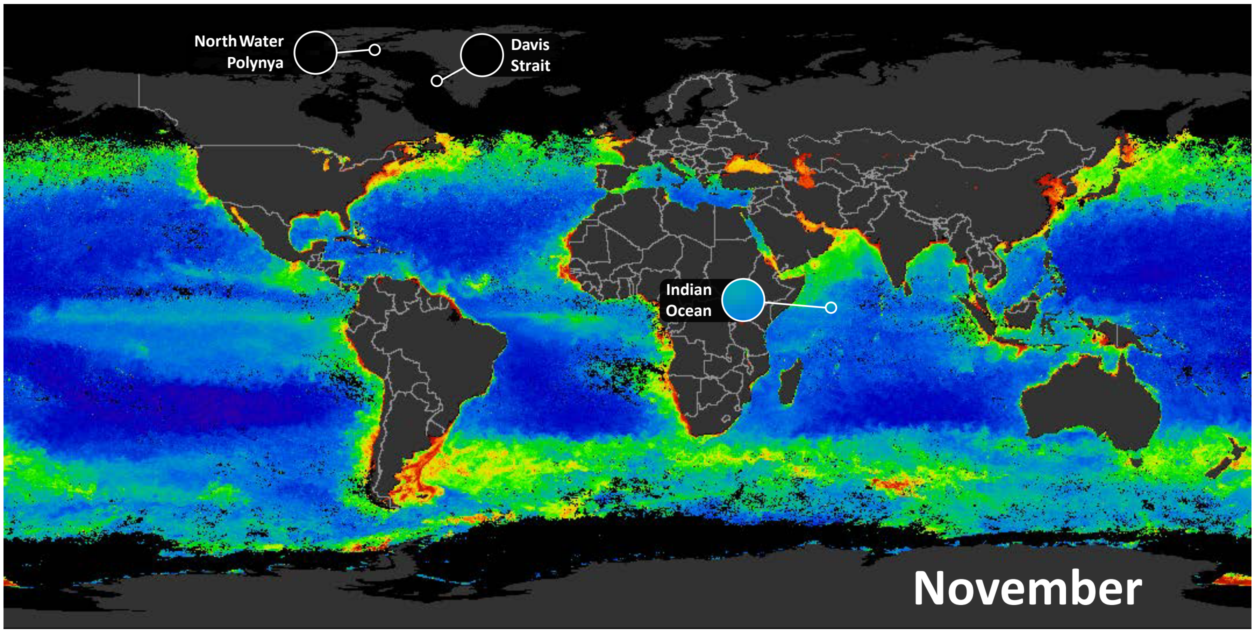
Concentration of chlorophyll a at surface (mg/m^3)

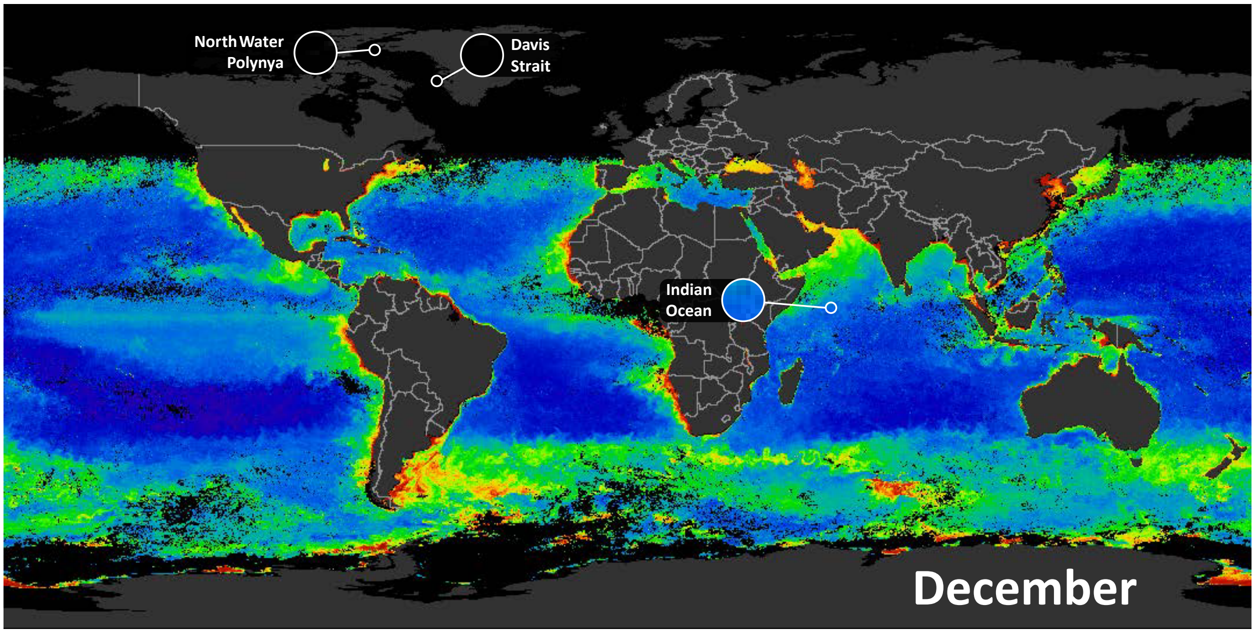


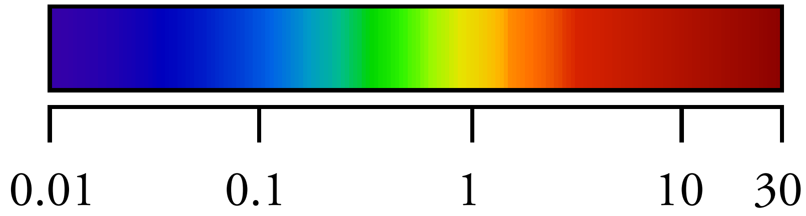




Concentration of chlorophyll a at surface (mg/m³)







Concentration of chlorophyll a at surface (mg/m³)

WORKSHEET

1. Choose 1 of the 3 locations on the Monthly Ocean Chlorophyll Concentration Maps (pg. 7).

   - (A) Northwater Polynya
   - (B) Davis Strait
   - (C) Indian Ocean

2. For each of the 12 months, use the logarithmic scale to estimate the Chlorophyll concentration value for your chosen location.
3. Record your value in *Table 1*.

Month	Indian Ocean Primary Productivity (mg/m3)	Davis Strait Primary Productivity (mg/m3)	North Water Polynya Primary Productivity (mg/m3)
Jan	0.4	0.01	0.01
Feb	0.3	0.01	0.01
Mar	0.18	0.01	0.01
Apr	0.11	0.9	0.56
May	0.085	3	3.7
Jun	0.28	0.8	2.1
Jul	0.4	1	1
Aug	0.54	0.63	1
Sep	0.65	0.57	0.01
Oct	0.57	0.01	0.01
Nov	0.17	0.01	0.01
Dec	0.15	0.01	0.01

TABLE 1 Using the Chlorophyll a concentration maps, record the logarithmic chlorophyll concentration values for each month. (Answer key - results will vary based a given student's perception of color on the map).

4. Plot your data from *Table 1* on *Figure 2*.

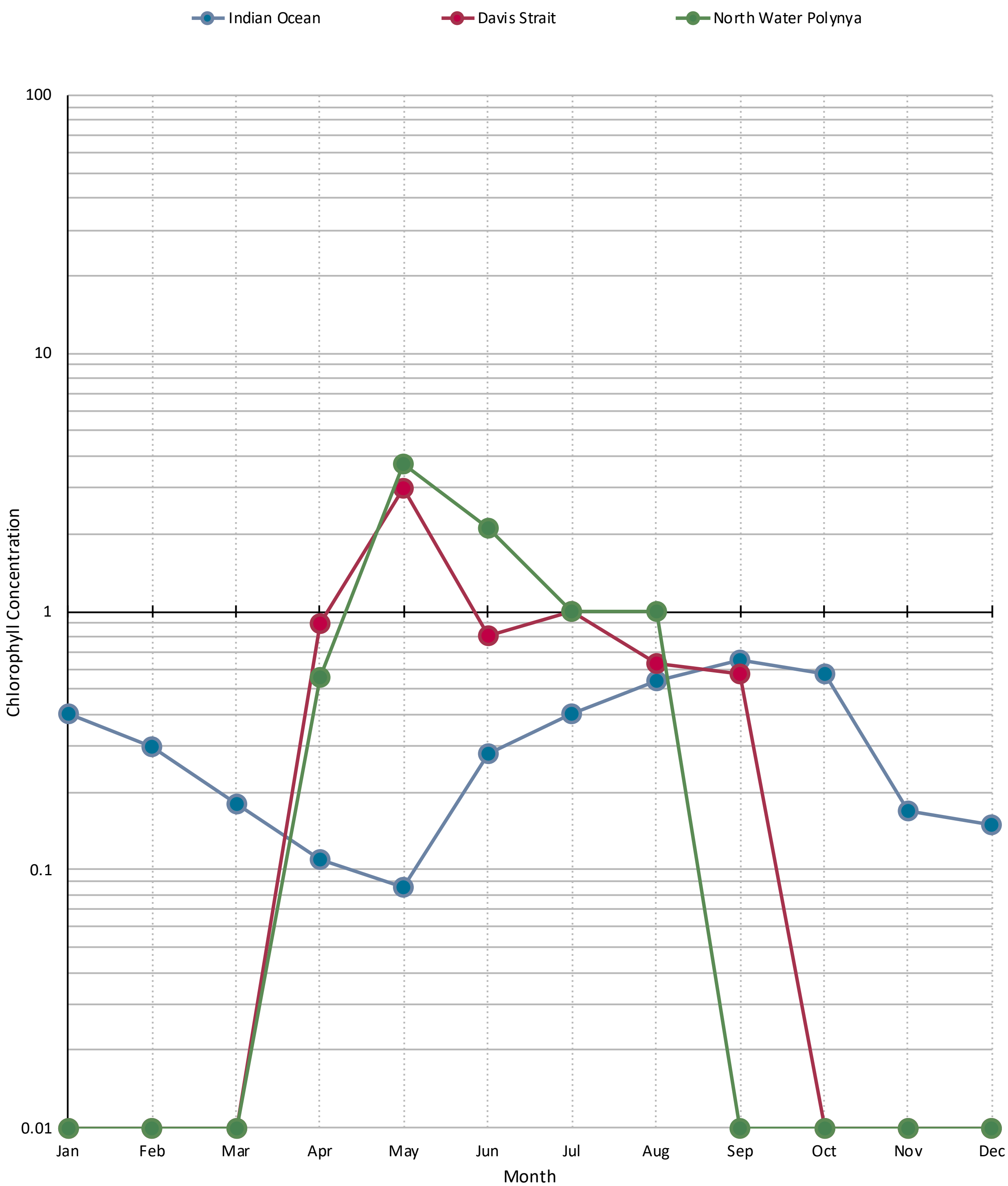


FIGURE 2 Plot your Chlorophyll a concentration values onto this logarithmic graph. (Answer key - there is no single right answer and each student will have a slightly different looking graph based on their estimation techniques.)

DISCUSSION QUESTIONS

1. How does phytoplankton indicate climate change?

   Phytoplankton require specific conditions for their prolific growth. Changes in climate (cooler or warmer), contaminants entering the ocean waters (spills), or altering levels of saline all affect their growth which can be monitored and measured from satellites.

2. How does sea ice influence primary productivity in arctic marine environments?

   Sea ice affects primary productivity by trapping nutrients and releasing them during the melting period, providing phytoplankton with the means to flourish. Sea ice also inhibits the sun's access to reaching open waters and largely prevents phytoplankton photosynthesis. Sea ice ensures that the growth of phytoplankton in arctic waters is seasonal.

3. How are the graphs for the locations different? Similar? Why?

   The graph from an area of the Arctic Ocean shows a spike in the summer due to the melting of sea ice, which increases the availability of light in comparatively nutrient rich surface waters and results in rapid growth of phytoplankton. The graph for the polynya should be similar to that for the Arctic Ocean, except that due to the earlier availability of sunlight, photosynthesis should start earlier. The graph for the tropical marine environment should have a more or less continuous and comparatively low amount of photosynthesis occurring, due to the relatively low nutrient surface water levels.

4. Discuss the different annual patterns of primary productivity (slow/continuous, rapid/pulse) and the implications these have for consumers. Why do so many bird and whale species migrate to the Arctic during the summer and return to tropical areas in the winter?

   Slow and continuous growth of phytoplankton exists in the temperate waters of oceans near the equator. The lack of cooler waters that cause upwells in these areas limits the amount of available nutrients. Although there is a constant supply of sunlight, the growth of phytoplankton remains slow but constant.

   In the cooler waters of the Arctic Ocean, upwells are significant, bringing many nutrients to the surface for phytoplankton consumption. However, due to the ice coverage, phytoplankton growth is seasonal. With the melting of the ice releasing additional nutrients and letting the sun reach the phytoplankton, its growth is prolific. Consumers have access to a bountiful food source during this time. However, they migrate towards more temperate areas in the winter when the ice and lack of sunlight prohibit phytoplankton growth.

LINKS

- **National Snow and Ice Data Center. Wildlife: Phytoplankton**
  Includes a detailed overview of the important role that phytoplankton play in the arctic ecosystem.
  https://arcticeider.com/links/ocp01
- **Earth Observatory, NASA. Chlorophyll**
  Animation of monthly chlorophyll concentrations of Earth's oceans from July 2002 to present. Also includes a concise overview of phytoplankton and the important role that they play in ocean productivity.
  https://arcticeider.com/links/ocp02
- **Earth System 5 - Phytoplankton**
  13 minute video with high quality visuals that demonstrate phytoplankton growth in the Amazon from ocean nutrient sources, and from Sahara desert sandstorms.
  https://arcticeider.com/links/ocp03
- **Ocean Color**
  Colour maps showing chlorophyll concentrations in the ocean for multiple years. Select the Level 1 & 2 Browser link.
  https://arcticeider.com/links/ocp04
- **Measuring Primary Productivity**
  A short online article detailing how to measure primary production and why it is important to do so.
  https://arcticeider.com/links/ocp05
- **NASA Ocean Colour Teachers' Resources**
  Additional teacher resources related to NASA's Ocean Colour project.
  https://arcticeider.com/links/ocp06
- **Khan Academy Logarithmic Scale**
  A short video explaining how to interpret and plot numbers on a logarithmic scale.
  https://arcticeider.com/links/ocp08

IMAGE 5 Because polynyas are such productive environments and attract a diversity of life, they are a common place to hunt seal and other wildlife. (J.Heath)

IMAGE 6 Algae surrounds a floating chunk of sea ice. (J. Heath)

SOURCES

Cover Photo by Ocean Color/NASA.

1 Phytoplankton concentrations in the North Water and Lancaster Sound on June 14, 2016 by David Fuglestad, 2016. https://commons.wikimedia.org/wiki/File:Primary_Productivity_6_14_2016.jpg. Used under CC BY-SA 4.0, https://creativecommons.org/licenses/by-sa/4.0.

2 Phytoplankton - the foundation of the oceanic food chain by NOAA MESA Project , 1973. http://www.photolib.noaa.gov/htmls/fish1880.htm. Used under CC BY-SA 3.0, https://creativecommons.org/licenses/by-sa/3.0.

ATTRIBUTION

PRIMARY

- Rian Dickson
- Karl Hardin

CONTRIBUTORS

- Karl Hardin
- Joel Heath
- Jackie Kidd
- Jennifer Provencher
- Misha Warbanski
- Evan Warner