PHYTOPLANKTON BIOGEOGRAPHY: WHERE IS MY HOME?

Lilly T. Blume
Virginia Institute of Marine Science

Grade Level
High School

Subject Area
Biology, Environmental Science
Oceanography

VA SEA is a collaborative project between the Chesapeake Bay National Estuarine Research Reserve, the Virginia Institute of Marine Science's Marine Advisory Program, and Virginia Sea Grant. The VA SEA project is made possible through funding from the National Estuarine Research Reserve System Science Collaborative, which supports collaborative research that addresses coastal management problems important to the reserves. The Science Collaborative is funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center.

Title: Phytoplankton Biogeography: Where is my Home?

Focus: Conceptualizing the basics of biogeography through the generation, visualization, and interpretation of a phytoplankton dataset.

Grade Level: High School Biology/High School Environmental Science

VA Science Standards:

BIO.1/ENV.1
The student will demonstrate an understanding of scientific and engineering practices by

c) interpreting, analyzing, and evaluating data
- construct and interpret data tables showing independent and dependent variables, repeated trials, and means
- construct, analyze, and interpret graphical displays of data

d) constructing and critiquing conclusions and explanations
- make quantitative and/or qualitative claims regarding the relationship between dependent and independent variables
- construct and revise explanations based on valid and reliable evidence obtained from a variety of sources including students' own investigations, models, theories, simulations, and peer review
- apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and design solutions

f) obtaining, evaluating, and communicating information
- compare, integrate, and evaluate sources of information presented in different media or formats to address a scientific question or solve a problem

BIO.2
The student will investigate and understand that chemical and biochemical processes are essential for life. Key ideas include

a) water chemistry has an influence on life processes

BIO.7
The student will investigate and understand that populations change through time. Key ideas include

b) genetic variation, reproductive strategies, and environmental pressures affect the survival of populations

ENV.5
The student will investigate and understand that the Earth is one interconnected system through which energy and matter flow. Key content includes

a) Earth's terrestrial and aquatic biomes have distinct characteristics and components

e) biotic and abiotic factors may limit population growth in a given area (carrying capacity)

ENV.6
The student will describe that stability and change impact both populations and ecosystems. Key content includes

g) changes in the hydrosphere, atmosphere, geosphere, or anthrosphere impact the biosphere

ENV.11 The student will investigate and understand that global climate change is occurring. Key content includes

d) consequences of climate change will affect the biosphere on many levels including species migration and extinction, disease spread, and ecosystem health (e.g. bleaching corals and dying forests)

Learning Objectives:

⇒ Students will orient themselves on a world map and identify ocean basins, hemispheres, and latitudes.
⇒ Students will generate their own phytoplankton abundance data by following a scientific "sampling" procedure; and will visualize, analyze, and interpret this data.
⇒ Students will interpret data from various additional graphs supplied and combine this information with their own generated data to decipher where each phytoplankton lives on the world map.
⇒ Students will critically evaluate how phytoplankton biogeography is influenced by a changing climate and translate how the concept of biogeography applies to other organisms.

Total Length of Time required for the Lesson:

Preparation of materials: ~60 minutes
Actual lesson: ~90-120 minutes

- 15 minutes of introduction, 5 minutes of Group Activity 1, 5 minutes of review, 30 minutes of Group Activity 2, 5 minutes of review, 15 minutes of Group Activity 3, 10 minutes of review, 30 minutes of Individual Group Activity 1*, 5 minutes of conclusion.
  *May be provided as homework.

Vocabulary:

- **Abiotic factors:** Physical factors (non-living) that shape the environment. Examples are temperature, salinity, and nutrients.
- **Biogeography:** Study of the geographic distribution of living organisms and factors that determine this distribution.
- **Biotic factors:** Biological factors (living) that shape the environment. Examples are co-existing organisms, such as fish and bacteria.
- **Climate change:** Naturally and anthropogenically (human) caused long-term changes in weather patterns and temperature.
- **Cyanobacteria:** Prokaryotic single-celled phytoplankton. Generally, much smaller in size than diatoms and dinoflagellates. Sole primary producers. Example genus is ***Prochlorococcus***.
- **Diatoms:** Eukaryotic single-celled, non-motile phytoplankton. Sole primary producers. Example genus is ***Chaetoceros***.
- **Dinoflagellates:** Eukaryotic single-celled, often motile phytoplankton. Can be primary producers and primary consumers. Example genus is ***Pyrodinium***.
- **Ecosystem:** Interconnected system between living organisms and the physical environment they live in.
- **Equator:** Degree (°) at which latitude is 0. Equal distance from both poles. Dividing Earth into southern and northern hemisphere.

- **Functional group:** In phytoplankton biology, groups that have functionality in common and share characteristics. Examples are diatoms, dinoflagellates, and cyanobacteria.
- **Genus:** Taxonomic category above species. Example *Chaetoceros*, *Pyrodinium*, *Prochlorococcus*.
- **Habitat:** An organism's natural home or environment in which it lives.
- **Hemisphere:** Divided into northern and southern by equator (latitude 0°). Separates Earth into two halves.
- **Latitude:** Refers to distance from the equator. High latitude is towards pole, low latitude is towards equator.
- **Nutrients:** Compounds required by all living organisms for growth and maintenance.
- **Oceanic food web:** Shows interdependent feeding relationships. Most phytoplankton are on the bottom as primer producers. They provide food for consumers, such as small fish. Small fish are consumed by bigger fish. All organisms found in the ocean ecosystem form part of this web.
- **Phytoplankton:** Microscopically small primary producers in the ocean (and all other aquatic ecosystems) that produce oxygen.
- **Primary consumers:** Organisms that feed on primary producers.
- **Primary producers:** Organisms that produce their own food using sunlight and inorganic compounds and convert them into organic compounds. Form the bottom of the oceanic food web.
- **Salinity:** Concentration of salt in water. Often reported in *parts per thousand* (ppt).
- **Sea surface temperature:** Temperature (in °C) of the ocean's surface water.
- **Species:** Taxonomic category below genus.
- **Triplicate:** 3x replication in sampling to decrease bias in data.

Background Information:

Phytoplankton are found across all ocean basins. They are microscopically small organisms that dominate primary production in our ocean, and hence, Earth. As primary producers, phytoplankton convert carbon dioxide into oxygen. Much of the oxygen that we breath was produced by phytoplankton. As primary producers, phytoplankton are found at the bottom of the oceanic food web, where they serve as prey for primary consumers. "Phytoplankton" is a very generic term. Phytoplankton can be divided into various functional groups, and thousands of species. These groups and species are not homogenously distributed in our ocean. Phytoplankton distribution is driven by a variety of abiotic and biotic factors. Examples of abiotic factors that determine geographical distribution and habitat are nutrients, salinity, and sea surface temperature. Slowly, we start to drift into the concept of biogeography. Biogeography is the study of the geographical distribution of animals, plants, and other living organisms, and the factors that drive this geographical distribution. In this lesson, we will focus on geographical distributions within biogeography only, and will not discuss the evolutionary approach, which would require an additional lesson.

Three major phytoplankton groups are diatoms, dinoflagellates, and cyanobacteria. This list is by no means exhaustive. Diatoms and dinoflagellates are eukaryotes and cyanobacteria are prokaryotes. Within these groups you find many genera. Those that we will focus on are *Chaetoceros* (diatom), *Pyrodinium* (dinoflagellate), and *Prochlorococcus* (cyanobacterium). The three genera are largely different in their nutritional needs and resource acquisition. Non-surprisingly, they often prefer different geographic locations. *Chaetoceros* prefers nutrient-rich, high-latitude waters with cold sea surface temperatures. *Pyrodinium* thrives in coastal, nutrient-rich waters with warm sea surface temperatures. *Prochlorococcus* also prefers warm sea surface temperatures, but in association with a nutrient-poor open ocean environment.

Strong links between environmental conditions and phytoplankton become evident. This link is of particular concern in the face of climate change. Climate change, which is associated with warming sea surface temperatures, the intensification of extreme weather events, and ocean acidification, may impact and shift these environmental conditions that phytoplankton are acclimated to. This will ultimately impact phytoplankton biogeography. In this lesson, students will interactively match phytoplankton genera with geographic locations based on their own generated data and provided background information. They will become scientists for a day and will work in teams to solve the puzzle of where each phytoplankton's home is, after an unfortunate mix-up in the laboratory.

Materials & Supplies:

- Small brown paper bags. Thicker material will allow for multiple re-uses.
- Plastic pony beads in blue, red, and yellow. (See **Appendices** for lower cost bean option.)
- Black sharpie pen.
- White paper for color or black-and-white printing.
- Calculators.
- Blue, red, and yellow pens/pencils/markers. If each student has their own pens, then there is no need to acquire them.
- Computer and projector set-up.

Optional: Laminator for re-use of certain worksheet sets or print-out of PowerPoint Slide 12.

Teacher Preparation:
Example set-up for a class of 24 students. (8 groups with 3 students each.)

- Label brown paper bags "Sample 1", "Sample 2", and "Sample 3" with black sharpie pen.
    - If labelling 24 bags, you should end up with 8 bags labelled "Sample 1", 8 bags labelled "Sample 2", and 8 bags labelled "Sample 3".
- Fill bags with colored plastic beads.
    - "Sample 1" – 40 yellow beads, 10 blue beads, 5 red beads
    - "Sample 2" – 10 yellow beads, 5 blue beads, 40 red beads
    - "Sample 3" – 5 yellow beads, 40 blue beads, 10 red beads

- Print and cut out the "Phytoplankton Info Cards". Each group requires one set of info cards. For 8 groups, you should print them 8 times. These can be re-used. Laminate if possible.
- Print out 8 worksheet sets for Group Activity 1-3.
- Print out 24 worksheets for Individual Activity.

- Optional: Print out handout “Group Activity 3 – Information in Graphs” for use in conjunction with PowerPoint Slide 12. Each group requires one print out. This can be re-used. Laminate if possible.

1. Divide the students into groups of 3. If the number of students cannot be divided by 3, then some groups of 2 or 4 students may be formed (2 students per group raises the difficulty level). Each group should have enough table space to spread out and count beads.
2. Make sure that each student group has three differently colored pens, preferably blue, red, and yellow, to match up with the bead colors in the brown bags. In addition, each group should have a shared calculator.
3. Each group will receive one set of Group Activity 1, 2, and 3 worksheets and “Phytoplankton Info Cards” (printed out in color or black-and-white). Each student will receive one Individual Activity worksheet. Worksheet sets and info cards will be distributed as the lesson progresses.
4. Each student group requires 3 pre-prepped brown paper bags. These are the bags that contain certain ratios of blue, red, and yellow plastic beads. Once it’s time to hand them out, make sure that each student group receives a bag labeled “Sample 1”, “Sample 2”, and “Sample 3”.

Procedure:

Note: The adjoining PowerPoint presentation has a suggested informational dialogue in the notes section that you may follow.

1. Start the PowerPoint presentation and lesson on Slide 1 and follow through to Slide 7.
(~15 minutes)

- Optional: You can start by introducing who created this lesson. During this lesson, students will be scientists for a day and an introduction to a scientist may encourage them. (Slide 2)
- Continue by clarifying today’s mission. What is the purpose of this lesson and what can students expect? (Slide 3)
- Start to introduce phytoplankton and why we care about phytoplankton. (Slides 4-5)
- Then introduce abiotic factors. This will provide an easy transition into the concept of biogeography. (Slide 6)
- Before providing the definition on slide 7, you may want to brainstorm with your students what biogeography entails. Ask if they can think of keywords that are connected to biogeography, or if one of them even knows a definition!

2. Move into Group Activity 1 – Understanding the “Geography” in “Biogeography” (Slide 8).
(~5 minutes)

- Hand out the worksheet set with the Group Activity 1-3. These can be printed out in black-and-white and should be stapled together. One student group (3 students each) should receive one single worksheet set.
- In groups, your students will start the first exercise. This exercise is short and is meant to warm them up.
- Reiterate that before we can fully understand biogeography, we must first be able to know how to orient ourselves on a world map.

3. Continue the PowerPoint presentation on Slide 9.
(~5 minutes)

- Check with your students if they labeled the ocean basins and hemispheres correctly.

4. Move into Group Activity 2 – Sampling Phytoplankton (Slide 10).
(~30 minutes)

- Make sure that before starting this activity, your students have the appropriate tools. They should already have the worksheet set from Group Activity 1. They will need one calculator per group and colored pens/pencils/markers (yellow, red, and blue).
- Hand out the pre-prepped paper bags, the "Samples". Make sure that each student group received a "Sample 1" bag, a "Sample 2" bag, and a "Sample 3" bag.
- You may ease them into the exercise and set the scene by reading the instructions on the worksheet.
- This activity is carried out in groups. Students will need to work collaboratively to "sample" the bags and visualize the data. You may check that tasks are distributed evenly. It is suggested that roles are not divided by the teacher, but that the students will figure out how to divide the different tasks.

5. Continue the PowerPoint presentation on Slide 11.
(~5 minutes)

- Before reviewing results, discuss with your students why each bag was sampled three times. Can they mention benefits? This question will later be reviewed in the Individual Activity.
- If students collected, recorded, and visualized the data correctly, they should find the same answers as displayed on Slide 11.

6. Move into Group Activity 3 – Where is my Home? (Slide 12).
(~15 minutes)

- Make sure that each student group has received the "Phytoplankton Info Cards".
- In this exercise, students will use answers from their own-generated phytoplankton dataset, information from the "Phytoplankton Info Cards" and different types of abiotic-parameter-displaying graphs to deduce where each phytoplankton's home is. They may do so in groups. Keep Slide 12 on display whilst students are solving this exercise.
  Optional: Provide a printed out copy of Slide 12. A print-friendly version is found under **Handouts**, titled "Group Activity 3 – Information in Graphs".

7. Continue the PowerPoint presentation on Slide 13 and follow through to Slide 14.
(~10 minutes)

- You may display the answers one by one and may quickly discuss why groups came to this conclusion. (Slide 13)
- Introduce the topic of climate change and show how it is connected to the concept of biogeography and phytoplankton. (Slide 14)

8. Move into Individual Activity 1 – Applying your Knowledge (Slide 14).
(~30 minutes)

- This exercise will either be finished during class time or given as homework.
- If during class time, student groups will be broken up.
- Hand out the Individual Activity worksheet to each student.
- This exercise will allow your students to apply the new knowledge gained to real world problems and it will encourage them to think outside the box.

9. End the PowerPoint presentation and lesson on Slide 15.
(~5 minutes)

- Tell them that they fulfilled their mission and that they carried out a scientific investigation.

Assessment:

Students will be assessed on their ability to complete Group Activities 1 to 3 (data generation, visualization, and interpretation) in a group setting to reach a conclusion of where each phytoplankton was sampled from. Individual performance and application of newly gained knowledge will be assessed through a set of open-end/short-paragraph worksheet questions.

References:
For scientific background information used within the lesson plan document and presentation.

Flombaum, P., Gallegos, J. L., Gordillo, R. A., Rincón, J., Zabala, L. L., Jiao, N., Karl, D. M., Li, W. K. W., Lomas, M. W., Veneziano, D., Vera, C. S., Vrugt, J. A., & Martiny, A. C. (2013). Present and future global distributions of the marine Cyanobacteria *Prochlorococcus* and *Synechococcus*. *Proceedings of the National Academy of Sciences*, *110*(24), 9824–9829.

Malviya, S., Scalco, E., Audic, S., Vincent, F., Veluchamy, A., Poulain, J., Wincker, P., Iudicone, D., de Vargas, C., Bittner, L., Zingone, A., & Bowler, C. (2016). Insights into global diatom distribution and diversity in the world's ocean. *Proceedings of the National Academy of Sciences*, *113*(11).

Morquecho, L. (2019). *Pyrodinium bahamense* One the Most Significant Harmful Dinoflagellate in Mexico. *Frontiers in Marine Science*, *6*.

Handouts:

- Phytoplankton Info Cards
- Group Activity 3 – Information in Graphs

Student Worksheets and Answer Keys:

Group Activity Worksheet Set

- Group Activity 1: Understanding the "Geography" in "Biogeography"
- Group Activity 2: Sampling Phytoplankton
- Group Activity 3: Where is my Home?

Answer Key – Group Activity Worksheet Set

- Answer Key Group Activity 2: Sampling Phytoplankton
- Answer Key Group Activity 3: Where is my Home?
  (and Answer Key Group Activity 1: Understanding the "Geography" in "Biogeography")

Individual Activity Worksheet

- Individual Activity: Applying your Knowledge

Answer Key – Individual Activity Worksheet

- Answer Key Individual Activity: Applying your Knowledge

Info card **Diatom** *Chaetoceros*

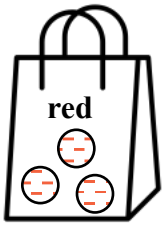
- Cold sea surface temperatures
- High latitudes
- Nutrient rich
  - Nutrient A and C
- Coastal and open ocean
- Low to high salinity

Sample 1
Diatom-dominated

Info card **Dinoflagellate** *Pyrodinium*

- Warm sea surface temperatures
- Low latitudes
- Nutrient rich
  - Nutrient A
- Coastal ocean
- Medium to high salinity

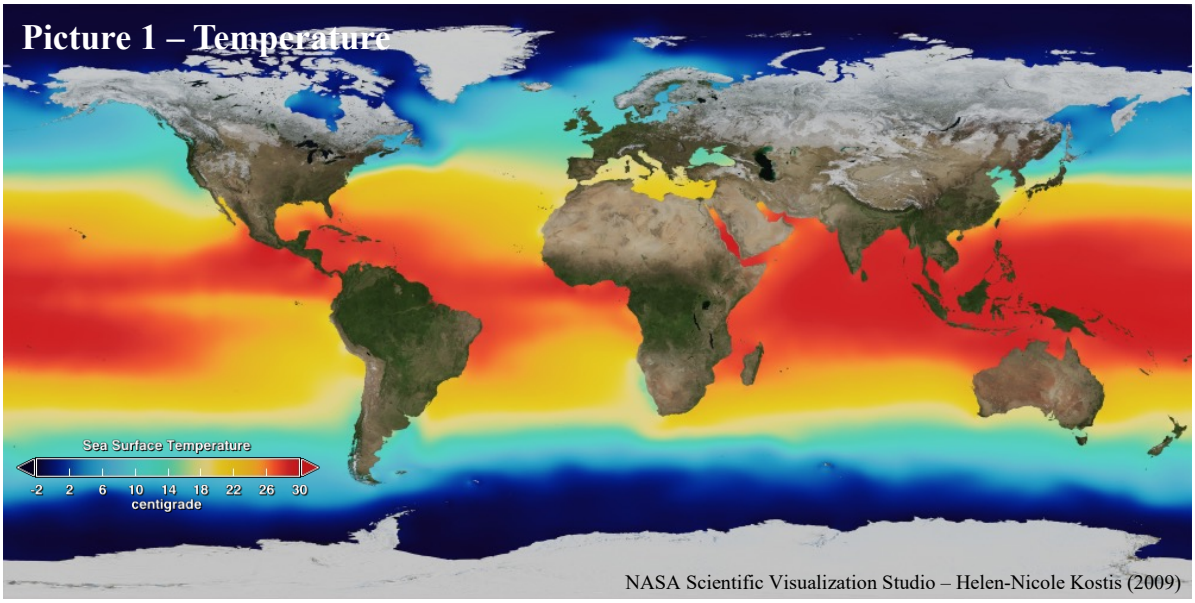
Sample 2
Dinoflagellate-dominated

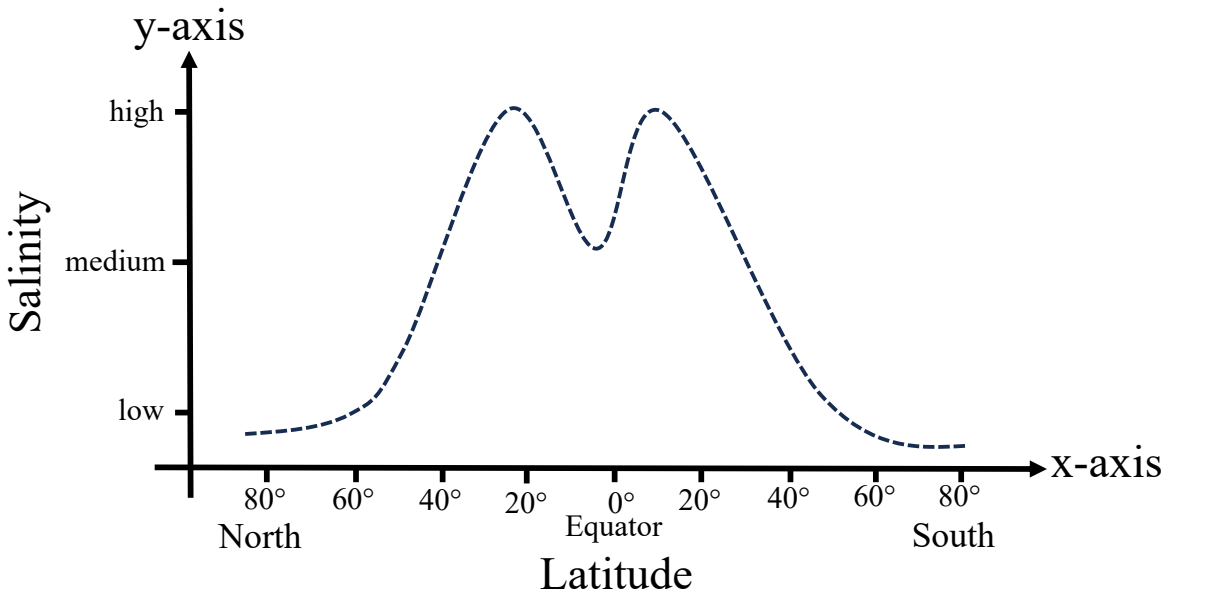


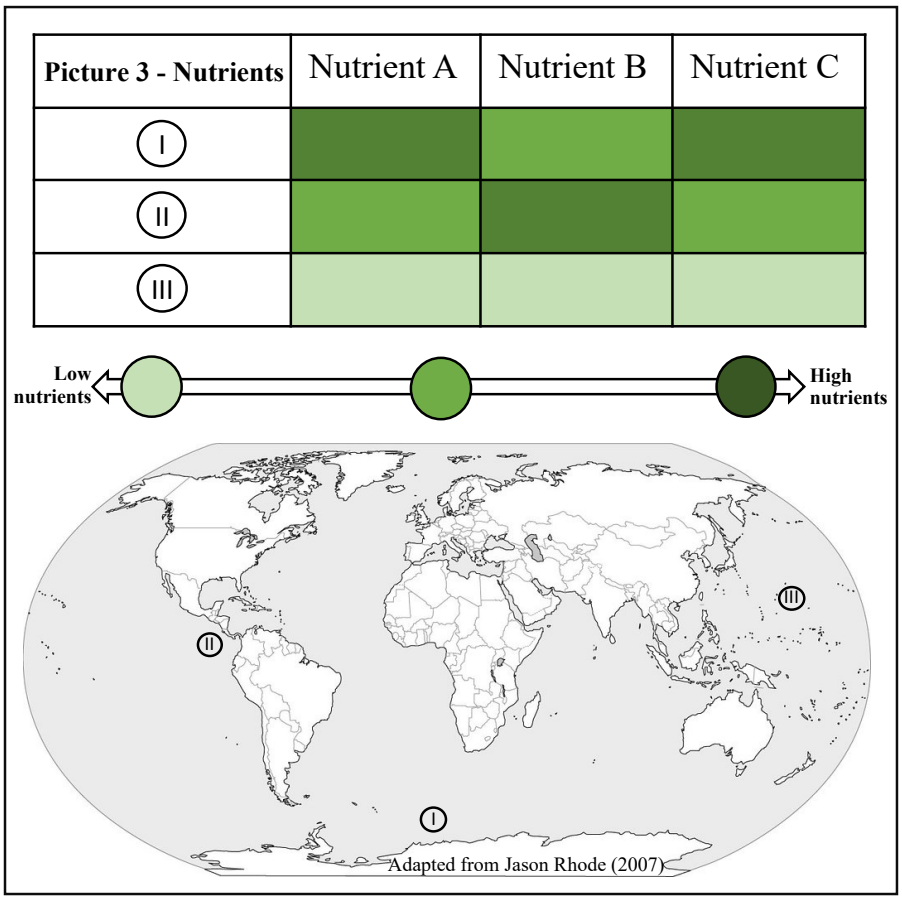
Info card **Cyanobacterium** *Prochloro-coccus*

- Warm sea surface temperatures
- Low to mid latitudes
- Nutrient poor
  - Nutrient B
- Open ocean
- High salinity

Sample 3
Cyanobacterium-dominated


Picture 1 – Temperature
Sea Surface Temperature
-2 2 6 10 14 18 22 26 30
centigrade
NASA Scientific Visualization Studio – Helen-Nicole Kostis (2009)


Picture 2 - Salinity
y-axis
high
medium
low
Salinity
x-axis
80° 60° 40° 20° 0° 20° 40° 60° 80°
North
Equator
South
Latitude

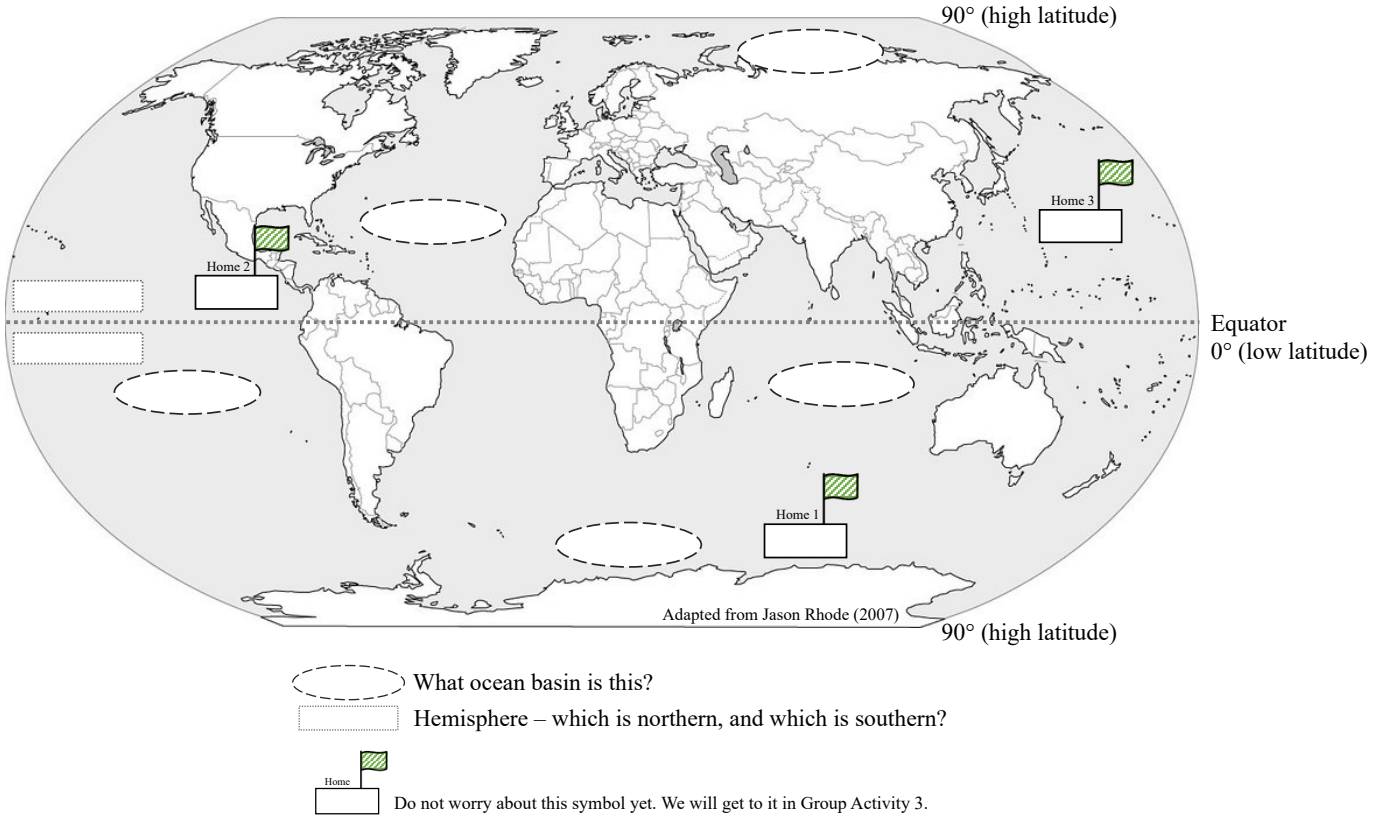

Picture 3 - Nutrients
Nutrient A
Nutrient B
Nutrient C
I
II
III
Low nutrients
High nutrients
II
III
I
Adapted from Jason Rhode (2007)

Group Member Names: _____ Date: _____

Group Activity 1: Understanding the "Geography" in "Biogeography"

Before we learn more about phytoplankton and where they live, it is a crucial skill for any scientist to be able to read a world map! Together with your group, go ahead and follow steps 1 and 2.

1. Fill in the ocean basins.
2. Label the northern hemisphere and the southern hemisphere.



STOP here and wait for your teacher's instruction before continuing with Group Activity 2.

Group Activity 2: Sampling Phytoplankton

You now know how to orient yourself on a world map, and you have just been provided with some information about phytoplankton. Great! Let the sampling begin.

In front of you, your group has 3 brown paper bags labelled "Sample 1", "Sample 2", and "Sample 3". Each bag represents a water sample containing many phytoplankton that was handed over to you by a fellow scientist who went on a research cruise around the world. Unfortunately, the

samples got mixed up! Your colleague does not remember anymore where each water sample was collected. Luckily, we know how to classify each phytoplankton.

Yellow = Diatom
Red = Dinoflagellate
Blue = Cyanobacteria

1. Together with your group, "sample" each bag. You do so by grabbing inside the bag and pulling out 10 beads.
2. Record the number of bead colors that you pull from each bag in the table below. Please return the beads to the bag before sampling a second time.
3. Repeat this for a total of 3 times for each bag. This repetitive sampling is also referred to as a "triplicate". It reduces bias in sample collection.
4. How many Diatoms, Dinoflagellates, and Cyanobacteria are found, on average, in each of your grab samples? Calculate and add value to column "Average". Round up to one decimal place.

Sample 1	1St grab sample	2nd grab sample	3rd grab sample	Average
Yellow (Diatom)				
Red (Dinoflagellate)				
Blue (Cyanobacterium)				

Sample 2	1St grab sample	2nd grab sample	3rd grab sample	Average
Yellow (Diatom)				
Red (Dinoflagellate)				
Blue (Cyanobacterium)				

Sample 3	1St grab sample	2nd grab sample	3rd grab sample	Average
Yellow (Diatom)				
Red (Dinoflagellate)				
Blue (Cyanobacterium)				

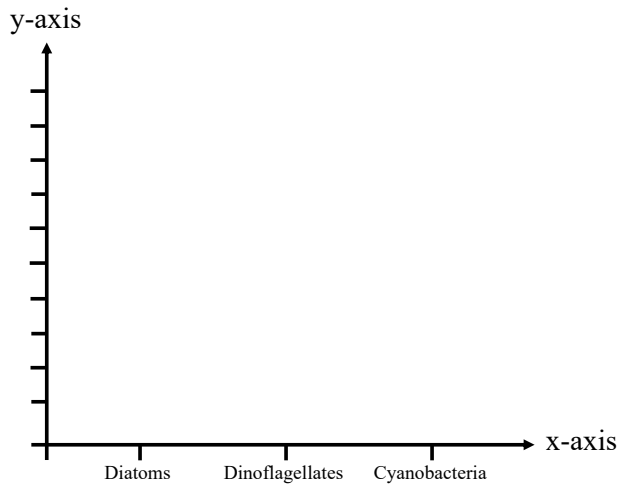
Are your tables filled in? Then now it's time to plot! Get your colored pens out!

1. Below you will find 3 empty graphs, one for each sample. Each graph has a y-axis and x-axis. The x-axis is already labelled for you. But the y-axis is still in need of labelling. Do so by finding an appropriate number range. Each of your graphs should have the same number range. This will allow for easier comparison between Samples 1, 2, and 3.

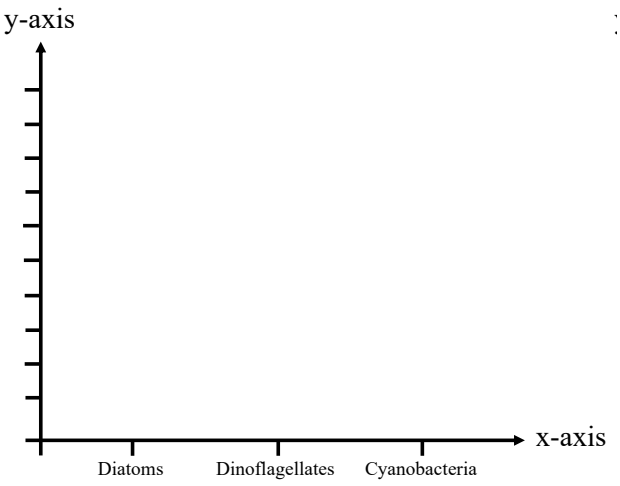
2. You may now start to add data to each graph, in form of a bar plot. The data that you want to add are the averages you calculated above. Don't forget to use a yellow pen to represent the yellow beads (Diatoms), a red pen to represent the red beads (Dinoflagellates), and a blue pen to represent the blue beads (Cyanobacteria). If you are a group of 3, each student should fill in a graph.

Reminder: Make sure that you do not mix up the samples! The "Sample 1" bag and "Sample 1" table should correspond with the "Sample 1" graph.

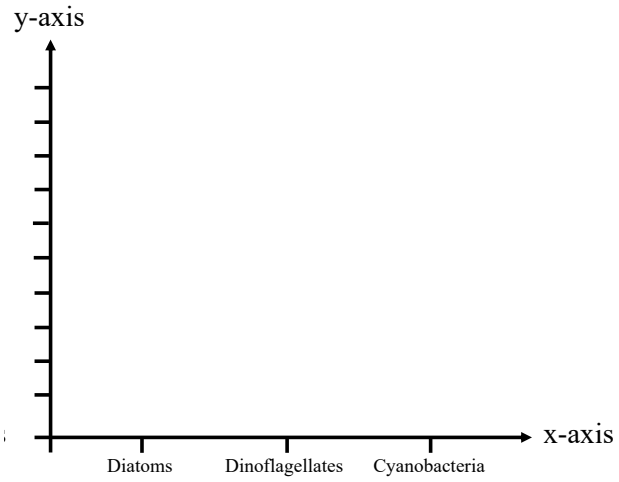
Sample 1



Sample 2



Sample 3



3. Now that you have the data in a table AND you have plotted it on graphs, it should be easy for your group to tell what sample is dominated by what phytoplankton group. Fill in the "Phytoplankton Group" column in the table below.

	Phytoplankton Group	Phytoplankton Genus (Leave this column blank until you get to Group Activity 3 and have received the Phytoplankton Info Cards.)
Sample 1		
Sample 2		
Sample 3		

STOP here and wait for your teacher's instruction before continuing with Group Activity 3.

Group Activity 3: Where is my Home?

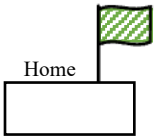
And now to the important part. Where was each water sample that was brought to you by your colleague collected? To figure this out, your teacher will share 3 different graphs with you.

Picture 1: Sea surface temperature
Picture 2: Salinity
Picture 3: Nutrient distribution

In addition, you will have received "Phytoplankton Info Cards". These correspond to your samples. Each info card indicates the name of a specific genus found within each phytoplankton group (*italicized*) and provides information on the environmental conditions the phytoplankton genus in your sample thrives in.

1. Fill in the "Phytoplankton Genus" column in the above table from Group Activity 2.

With the help of the 3 graphs shared by your teacher, you will be able to figure out where in the world's ocean each phytoplankton sample originates from. Go back to the world map under Group Activity 1. Do you remember this symbol?



2. Match up the phytoplankton sample with the location it was collected at. On the world map, this location is referred to as "Home". One phytoplankton sample was collected at "Home 1", one at "Home 2" and one at "Home 3". Enter the sample number (e.g., Sample

1) with the associated phytoplankton genus (e.g., *Chaetoceros*) into the symbol box on your map.

Your team did it! You were able to figure out where each sample was collected and found each phytoplankton's home! At the same time, you have learned about phytoplankton and the concept of biogeography, and why these matter. Well done!

Answer Key Group Activity 2: Sampling Phytoplankton

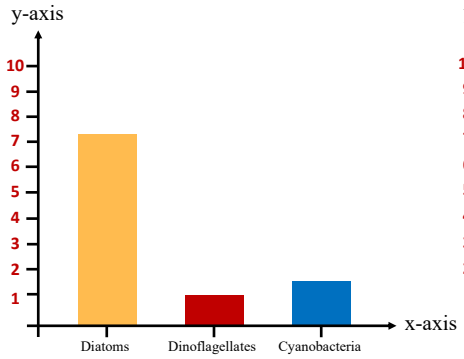
The answers recorded will vary, as they are based on the beads that are pulled out of each bag. Below, you will find an example table and graph for "Sample 1", "Sample 2", and "Sample 3". Averages should be rounded to one decimal place. This decimal place should be accounted for in the plot.

Sample 1	1St grab sample	2nd grab sample	3rd grab sample	Average
Yellow (Diatom)	**7**	**6**	**9**	**7.3**
Red (Dinoflagellate)	**1**	**2**	**0**	**1**
Blue (Cyanobacterium)	**2**	**2**	**1**	**1.7**

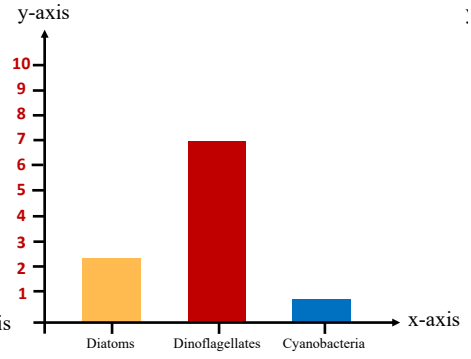
Sample 2	1St grab sample	2nd grab sample	3rd grab sample	Average
Yellow (Diatom)	**2**	**3**	**2**	**2.3**
Red (Dinoflagellate)	**8**	**6**	**7**	**7**
Blue (Cyanobacterium)	**0**	**1**	**1**	**0.7**

Sample 3	1St grab sample	2nd grab sample	3rd grab sample	Average
Yellow (Diatom)	**0**	**1**	**1**	**0.7**
Red (Dinoflagellate)	**1**	**2**	**1**	**1.3**
Blue (Cyanobacterium)	**9**	**7**	**8**	**8**

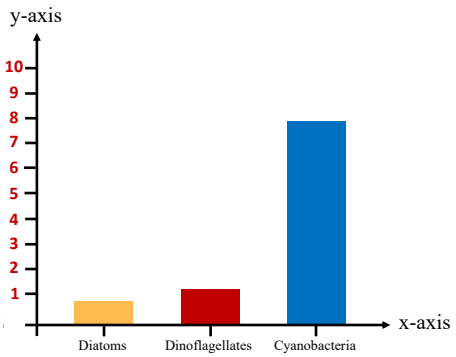
Sample 1



Sample 2



Sample 3

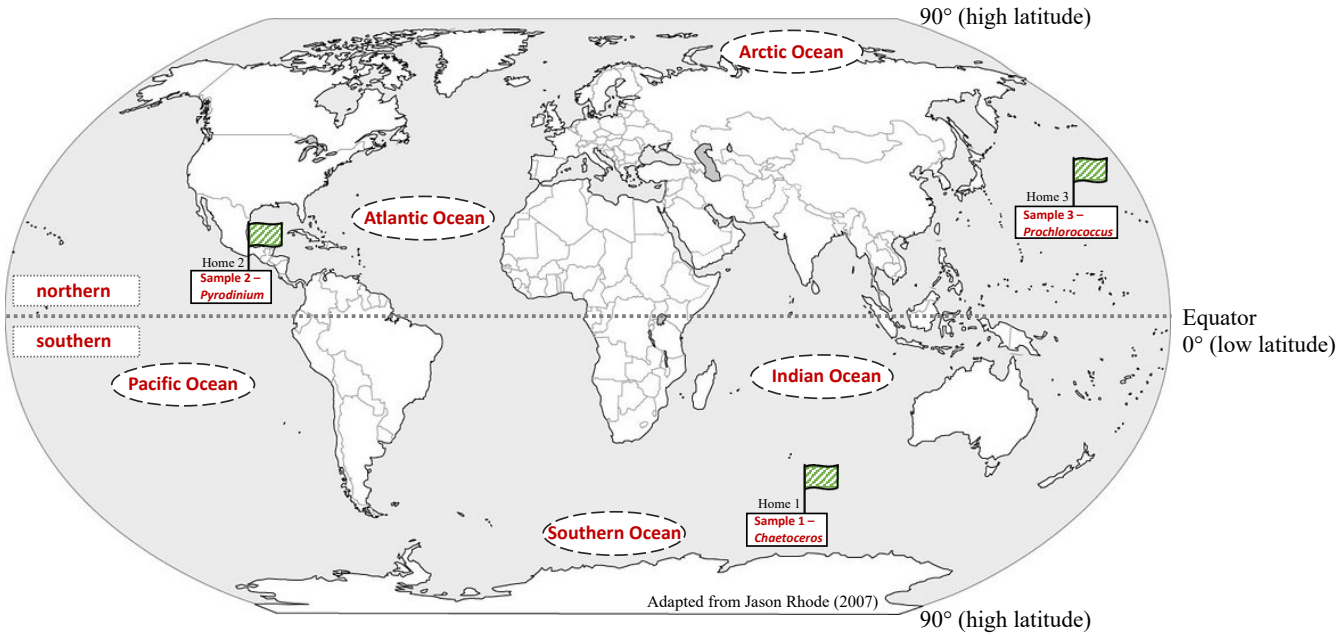


Below is the answer to which sample bag was dominated by which phytoplankton group. Every student group should arrive at the same conclusion, independent if their averages differ.

	Phytoplankton Group	Phytoplankton Genus (Leave this column blank until you get to Group Activity 3 and have received the Phytoplankton Info Cards.)
Sample 1	**Diatom (yellow)**	***Chaetoceros***
Sample 2	**Dinoflagellate (red)**	***Pyrodinium***
Sample 3	**Cyanobacteria (blue)**	***Prochlorococcus***

Answer Key Group Activity 3: Where is my Home?
(and Answer Key Group Activity 1: Understanding the "Geography" in "Biogeography")

Below is the answer to where each phytoplankton's home is. Answers should be provided as genus.



Name: _____ Date: _____

Individual Activity: Applying your Knowledge

Scientists use their acquired knowledge and apply it to pressing real world problems that need solving. With the understanding about phytoplankton biogeography that you have just gained, try and answer the following questions. Not all questions have a correct answer. Some are meant to make you think.

This is an individual exercise. Do not work in groups.

1. Why do we sample in triplicate? List some advantages.

2. Temperature, salinity, and nutrients are only some of the variables that influence phytoplankton biogeography. Can you think of others? Name at least 1 (or 2) more.

3. One of the impacts of climate change is global warming.
    a. If sea surface temperatures increase, how do you think the biogeography of the phytoplankton you investigated in this lesson may change?

    b. If the biogeography of phytoplankton changes, can you think of any impacts this might have on the oceanic food web? Hint: Think about animals that feed on phytoplankton.

4. This lesson focussed specifically on phytoplankton biogeography, but there are many more organisms out there!
    a. Name you favorite marine organism.

    b. Do you know anything about your favorite organisms' biogeography? List.

    c. What would you like to learn about your favorite marine organism? Provide 2-3 things.

Answer Key Individual Activity: Applying your Knowledge

Scientists use their acquired knowledge and apply it to pressing real world problems that need solving. With the understanding about phytoplankton biogeography that you have just gained, try and answer the following questions. Not all questions have a correct answer. Some are meant to make you think.

This is an individual exercise. Do not work in groups.

1. Why do we sample in triplicate? List some advantages.

To decrease bias in sample collection and processing and catch environmental variation.

2. Temperature, salinity, and nutrients are only some of the variables that influence phytoplankton biogeography. Can you think of others?

Abiotic and biotic factors are correct to be listed here. Examples are oxygen, hydrodynamics, wind, currents, seasons, weather events, predation, co-existing microbes, and other animals/plants/phytoplankton.

3. One of the impacts of climate change is global warming.
    a. If sea surface temperatures increase, how do you think the biogeography of the phytoplankton you investigated in this lesson may change?

This is an open-ended question. There is not a clear answer. Purpose of this question is to apply knowledge acquired to real-world scenarios.

Example: If the sea surface temperature in higher latitudes rises, then those phytoplankton that are usually found in low tropical latitudes, such as the dinoflagellate *Pyrodinium*, may migrate as their range in habitat expands. At the same time, the diatom *Chaetoceros*, which prefers colder sea surface temperatures around the poles, might need to adapt to cope with these warmer temperatures. Changes in temperature are often associated with nutrient availability, and even salinity. For example, higher sea surface temperatures can change the stratification of the water column. Some phytoplankton are better adapted to this stratification, in which nutrients are often scarce. Cyanobacteria can cope with lower nutrient concentrations than e.g., diatoms.

    b. If the biogeography of phytoplankton changes, can you think of any impacts this might have on the oceanic food web? Hint: Think about animals that feed on phytoplankton.

This is an open-ended question. There is not a clear answer. Purpose of this question is to apply knowledge acquired to real-world scenarios.

Example: Phytoplankton form the bottom of the food web as primary producers. If their abundance changes because their geographic distribution shifts, then this may impact consumers higher up the food chain. Primary consumers that prefer a specific phytoplankton prey might have to adjust their nutritional need if the availability of their preferred prey changes.

4. This lesson focussed specifically on phytoplankton biogeography, but there are many more organisms out there!
    a. Name you favorite marine organism.

This answer will vary by student. For example, corals. (Either plant or animal is fine, as long as it is a living organism.)

    b. Do you know anything about your favorite organisms' biogeography? List.

Corals thrive in tropical regions that have warmer sea surface temperatures. But cold-water corals also exist! They need enough light for their symbionts to photosynthesize and produce food that the coral can use. The Great Barrier Reef is one of the largest coral reefs in the world.

    c. What would you like to learn about your favorite marine organism? Provide 2-3 things.

How corals are influenced by tourism (e.g., diving), sea-level rise, and increasing sea surface temperatures. Can corals recover once they suffered damage? Are fish affected by declining coral cover?

Appendices:

Optional: Switch out plastic pony beads for dried beans. Dried beans will lower the Materials & Supplies cost. Make sure to update your students on the color change, as worksheets will suggest the use of blue, red, and yellow pens.

Blue beads -> black beans
Red beads -> red beans
Yellow beads -> white beans