**Sample Primary Productivity Lesson**

This activity uses chlorophyll time series from several OOI arrays to investigate variability in primary production. The basic activity was designed for an Introduction to Oceanography course. We also provide examples of extending the basic activity to upper-level students. For the primary activity, students should be familiar with photosynthetic primary production, limiting factors for primary production in the ocean, and the concept of using chlorophyll-a concentration to indicate phytoplankton biomass.

*Learning goals*

At the end of this activity, students should be able to…

* Describe geographic and seasonal variation in primary production
* Identify patterns in realistic chlorophyll data that relate to primary production cycles
* Apply knowledge of limiting factors (nutrients, light, stratification) and evidence from data to develop hypotheses about primary production in different regions of the ocean

*Basic activity description*

Exercises are designed for one class period (50-75 minutes) of an introductory oceanography course, preceded by a short introduction. The instructor may provide an overview of the OOI mooring arrays using the diagrams supplied at the bottom of the Data Exploration pages. The basic activity, described on **Worksheet A,** guides the students through a comparison of chlorophyll data from different ocean regions. Each exercise consists of three basic elements:

1. *Exploration***:** Students familiarize themselves with the data by identifying maxima, minima, time periods, and seasonal variations.
2. *Conceptualization***:** Students are asked to identify patterns in realistic chlorophyll data that relate to primary production cycles, describe geographic and seasonal variation in phytoplankton biomass and primary production rates, and apply prior knowledge of limiting factors (nutrients, light, stratification).
3. *Interpretation***:** Students use insights gained from the data to develop hypotheses about primary production in different ocean regions.

Links to Data Explorations used in this activity:

* Chlorophyll Across the Year: <https://datalab.marine.rutgers.edu/explorations/productivity/activity2.php?level=exploration>
* Chlorophyll in Temperate Zones: <https://datalab.marine.rutgers.edu/explorations/productivity/activity4.php?level=concept_invention>
* Chlorophyll near Polar Zones: <https://datalab.marine.rutgers.edu/explorations/productivity/activity5.php?level=concept_invention>
* Chlorophyll Inshore vs. Offshore: <https://datalab.marine.rutgers.edu/explorations/productivity/activity6.php?level=application>

*Extended activity, option 1*

Nutrient limitation is an important concept taught in introductory oceanography units on primary production. This Data Exploration widget adds nitrate data: <https://datalab.marine.rutgers.edu/explorations/2019/chl_nitrate.php>

**Worksheet B** guides students through a comparison of nitrate and chlorophyll data at an open ocean (Irminger Sea) and a coastal (Washington Shelf) location.

*Extended activity, option 2*

In some undergraduate courses, particularly at more advanced levels, students may be asked to consider the oceanographic setting of the OOI mooring arrays. **Worksheet C** provides an example of using chlorophyll data from the near-polar arrays in a class in which the students have more advanced prior knowledge of ocean circulation, density stratification and seasonal cycles of primary productivity.

*Extended activity, option 3*

**Worksheet D** is a jigsaw activity designed for intermediate or upper-level undergraduate courses based on Palevsky and Nicholson (2018). This activity has also been tested at OOI Data Labs workshops for undergraduate professors. To conduct the jigsaw activity, divide students into three groups (or multiples of three). Each group examines one jigsaw piece: Temperature, chlorophyll, or dissolved oxygen. The groups then reconfigure to have one “expert” from each original group and then answer prompts (under *Bringing it Together*) to identify seasonal patterns in all three parameters.

*Teaching tips*

Students need access to a web browser and internet connection to use the interactive graphs. The interactive graphs can be viewed on tablets and smartphones, but laptops or desktop computers provide the best interactivity. If access to computers is not available, the data can be downloaded in CSV format from each Data Explorations page and printed as static graphs.

The graphs have sliders at the bottom to zoom in and out. On graphs with multiple data sets, each parameter can be turned on and off by clicking the appropriate box.

The bottom of each OOI Data Explorations page has a map and mooring diagrams of the location of the data, as well as a photo of a fluorometer.

Students at the introductory level often need assistance with the difference between identifying *evidence* to support an observation and proposing an *explanation* for an observed pattern.

The chlorophyll data from the Washington shelf (Endurance array) vary with coastal upwelling. If students have not previously learned about upwelling, or that upwelling supplies nutrients to the euphotic zone, they may struggle with interpreting the rapid fluctuations in chlorophyll.

*Resources*

Sample worksheets attached

Complete descriptions of the OOI arrays:
<https://oceanobservatories.org/research-arrays/>

Coastal upwelling definition:
<https://oceanservice.noaa.gov/facts/upwelling.html>

Paper on Irminger Sea productivity (source of data for Worksheet D):
<https://tos.org/oceanography/assets/docs/31-1_palevsky.pdf>

Video about one of the OOI arrays (Coastal Pioneer), and its role in investigating ocean productivity in coastal New England:
<https://www.whoi.edu/oceanus/feature/the-hotspot-for-marine-life>

Video with drone footage showing the deployment of OOI equipment at the Irminger Sea Array:
<https://www.youtube.com/watch?v=av8xodnoHnU>

**Worksheet A: Investigating primary production with OOI data**

1. Open the web link for *Chlorophyll in Temperate Zones* or *Chlorophyll Near Polar Zones*. Record your answers to these questions (circle the zone that you viewed):

1. How did the chlorophyll concentration vary over time in the [temperate/polar] zone?
2. What is your *evidence* for the pattern that you observed in the data over time?
3. What questions do you have about patterns in chlorophyll concentration over time in the [temperate/polar] zones of the ocean?

2. Open the web link for *Chlorophyll Inshore vs. Offshore*. Record your answers to the questions below.

a. Is there a relationship in primary production among the inshore and offshore locations?

* If so, what kind of relationship is it? Why do you think that relationship exists for chlorophyll concentration among the inshore and offshore locations?
* If not, why do you think there is no relationship for chlorophyll-a concentration among the inshore and offshore locations?

b. How does this relationship (or lack of relationship) support or challenge what you previously knew about primary production?

1. What questions do you still have about primary production?

3. If you have time, use the Excel data files supplied on Blackboard to plot your own graph of chlorophyll vs. time

Primary Production Data Exploration Collection: <https://datalab.marine.rutgers.edu/explorations/productivity/index.php>

**Worksheet B: Comparison of Chlorophyll-a and Nitrate**

Work in groups of 4-6 people, record answers individually in the space provided below. To begin the exercise, go to the following webpage:

<https://datalab.marine.rutgers.edu/explorations/2019/chl_nitrate.php>

First, familiarize yourself with the widget. The graph shows Chlorophyll-a and Nitrate data from two stations. You can find background information about the stations and the instruments being used to collect the data at the bottom of the webpage. Each parameter can be turned on and off by clicking the appropriate box. You can also move the sliders at the bottom to zoom in and out.

There are three parts to this exercise.

*Exploration 1 – Chlorophyll-a Washington shelf versus Irminger Sea*

1. Deselect all Nitrate data and describe the Chlorophyll-a data for the two stations by answering the following questions:
2. When is Chlorophyll-a highest at each station, when is it low? For how many months a year do you observe elevated Chlorophyll-a?
3. What is the maximum Chlorophyll-a concentration at each site, what is the lowest?
4. Do you observe any patterns? If so, what are the patterns? Are there similar patterns at each station?

*Exploration 2 – Comparison of Chlorophyll-a and Nitrate*

For this part please split your group into two smaller groups, where each sub-group will focus on one station. Describe the relationship between chlorophyll-a and nitrate for your station by answering the following questions:

1. Which station are you describing?
2. Are there similarities in the Chlorophyll-a and Nitrate distributions? Are there differences?
3. How does this relationship, or lack of relationship, support or challenge what you previously knew about primary production?
4. What other measurements would you propose to better understand this relationship?

*Interpretation and Analysis*

1. Rejoin with the other half of your group and compared your findings. We’ll continue the discussion with the whole class.
2. Compare your findings from Exploration 2: did you observe the same relationship at the two sites? If yes, how are they similar? If not, how are they different?
3. How would the additional measurements you propose help you to understand the relationships between nutrients and primary production?
4. What do you suggest causes the onset of primary productivity in each region? What is the major limiting factor? Is primary productivity limited by the same factor at the two sites, or are they different?
5. How does the pattern of productivity compare to the textbook schematic of seasonal changes over the course of a year?



**Worksheet C: Phytoplankton Blooms**

In this activity, you will compare the seasonal cycle of surface ocean chlorophyll concentrations observed at three of the Ocean Observatories Initiative arrays: the Irminger Sea, the Southern Ocean, and Station Papa.

1. First look at the locations of all three of these sites on the map. Briefly describe the oceanographic setting of each of these stations. Are they in a gyre? If so, in the middle or on the edge? Any major currents nearby? What would you expect to be the major nutrient limiting phytoplankton growth in each of these regions? (You may want to use the latitude and longitude coordinates given on the OOI website to find these locations on other maps we have looked at previously in class.)
2. Based on your prior oceanographic knowledge of these three regions, which stations would you expect to experience a spring phytoplankton bloom? If you expect multiple stations to experience phytoplankton blooms, which do you think will be largest? Explain the reasoning behind your hypotheses.
3. Now look at interactive plots of chlorophyll data measured at these three sites over a full year at <https://datalab.marine.rutgers.edu/explorations/productivity/activity5.php?level=application>.
You can use the slider bar to vary the time scale on the x-axis and switch which of the three sites are displayed in the plot. Based on these data, which sites have clear phytoplankton blooms and which do not? Is the answer not clear based on the data available at any of the sites?
4. Compare the site with the largest phytoplankton bloom with the site that has the smallest/least evident phytoplankton bloom. Draw a schematic plot for each site that shows the seasonal cycle of the phytoplankton biomass alongside your estimate of what you would expect for the limiting nutrient(s) concentrations, light availability, and zooplankton abundance. Using these schematic plots, explain why you think there are different patterns of phytoplankton growth at these two stations.

**Worksheet D: Irminger Sea Jigsaw Activity**

The full “OOI Irminger Sea Data Activity Worksheet” with graphs and an answer key is available here: <https://datalab.marine.rutgers.edu/wp-content/uploads/2020/01/Irminger-Activity-KEY_v2.docx>

This activity uses temperature, chlorophyll and oxygen data from the surface mixed layer of the Irminger Sea. Students first work in small group to examine one variable over time and answer these questions:

1. Describe the pattern(s) or other significant features you see in this dataset
2. Based on your prior oceanographic knowledge, what do you think is causing these patterns?

Groups then rearrange to have one expert on each variable and complete the *Bringing it Together* worksheet with the following questions:

1. Now compare the 3 datasets and the patterns and features observed in each. What connections can you make between the datasets and observed patterns to describe the seasonal cycle of productivity at the Irminger Sea OOI site?
2. Based on the seasonal cycles in the variables that were directly measured and your understanding of the controls on productivity in this region, we can begin to infer the seasonal cycle in properties that were not directly measured. Draw schematic plots that illustrates your hypothesized seasonal cycle at the Irminger Sea OOI site for: 1) light availability, 2) nitrate concentrations, and 3) zooplankton abundance.

Groups are provided with a graph of dissolved oxygen showing the observed and equilibrium concentrations to answer the final questions:

1. During what time of year does the oxygen concentration indicate that the rate of photosynthesis exceeds the rate of respiration?
2. In the second phase of the spring bloom, both chlorophyll and oxygen concentrations decreased from their maximum values. What processes led these concentrations to decrease?