Overview

This module is an introduction to the marine biological pump. The module will use representative organisms to demonstrate the interconnectivity between the biosphere and the global carbon cycle.

Focus Questions

1. How are photosynthesis and respiration related to the global carbon cycle?
2. How does the biological pump work to maintain the oceanic carbon reservoir?
3. What controls the biological pump?

Learning Goals

1. To relate the ocean’s primary producers to terrestrial plants as and acting as consumers of CO₂
2. To be introduced to a variety of globally important marine organisms
3. To understand how the biology of the ocean is important in the global carbon cycle
4. To understand why phytoplankton growth is limited in some areas of the ocean
5. To appreciate the ecological balance of a few different organisms contributing to the upkeep of the biological pump

Teacher Background

What is the biological pump? As we know, photosynthesis consumes CO₂ while respiration produces it. In the ocean, these two processes can be spatially separated. Net photosynthesis occurs in the sunlit (upper) portion of the ocean, while net respiration occurs deeper. As CO₂ dissolves in the ocean, it becomes available to phytoplankton that fix it into organic carbon (photosynthesis), or used to form calcium carbonate shells (CaCO₃). Some of this organic carbon (in the form biological matter) sinks and is consumed (respiration) or dissolves (in the case of CaCO₃ shells) in the deeper ocean. Because the deeper ocean does not come in contact with the atmosphere very often, it traps the carbon in the deeper ocean, creating a large reservoir of carbon. The biological pump is thought to be bottom-up limited, meaning that the ocean would be able to act as a larger sink for CO₂ if there were more phytoplankton growth. In this way, the marine biological pump is closely related to other biogeochemical cycles, especially nitrogen, phosphorus, and iron which make up the main nutrients needed by phytoplankton to grow.

Prior Knowledge

Students should be familiar with the importance of CO₂ as a greenhouse gas and be introduced to the different global carbon reservoirs. Students have been introduced to photosynthesis and respiration as important biologically important mechanisms, but may have not yet related this to the marine carbon cycle, except as an aspect of
short-term variability. Introduction to the solubility of CO$_2$ in the oceans would be helpful before this module, but not necessary.

**Procedures**

**PART 1: INTRODUCTION TO THE BIOLOGICAL PUMP**

*It may be helpful to assign pages 154-159 as reading from Kump et al. before this module.*

This portion of the module will include a presurvey and a lecture (power point) to introduce the students to the biological pump and nutrient limitation. To begin the lesson, give each student a presurvey (provided). Allow the students about 10 minutes to complete the survey, stressing that it is an anonymous survey.

Next it may be helpful to rewrite the equations for photosynthesis and respiration on a whiteboard so the students may refer back as necessary during the powerpoint. It would also be helpful to provide the slides to the students to follow along and take notes. The key words provided here are important for students to know to understand the powerpoint. They are introduced and defined in the powerpoint on the indicated slides.

The following are notes for the instructors to accompany the provided powerpoint

- **Photosynthesis and Respiration** - The powerpoint begins with a review of photosynthesis and respiration as chemical formulas. It is not important for students to memorize these, but to know which is a sink and which is a source for CO$_2$.
- **Photosynthesis and Respiration and atmospheric CO$_2$** - On the second slide of the Keeling curve, probe the students to identify how photosynthesis and respiration affect the Keeling curve (the short term variations). This is an example of how seasonal differences in photosynthesis and respiration can change atmospheric CO$_2$. Doc.
- **The ocean is a large carbon reservoir** - The ocean is a large and important carbon reservoir. Only the upper ocean is in equilibrium with the atmosphere (exchanging carbon), but the deep ocean holds much more carbon than both the upper ocean and the atmosphere. Remember that the deep ocean only comes in contact with the atmosphere every 1000 years and that the upper ocean is usually considered only the top 100 m while the deep ocean can be over 4000 m deep.
- **Photosynthesis and Respiration in the Ocean** - Much like land plants and animals, there are many organisms that photosynthesize and respire in the ocean – in fact, a huge amount of the global fixation of carbon takes place in the ocean!
- The following slides are taken from MBARI's lesson plans for introducing the biological pump. They go through the steps of the biological pump – can also be found here in a slightly different form:
- **Overview of the Biological Pump** (slide 19). Each of the organisms mentioned in the previous slides are here, but in a better representation. We will be coming back to this figure in Part III, so make sure that the students are very familiar with it. Also, this figure shows how this system is balanced by upwelling. Stress that the pump is not a sink for carbon, but rather just a mechanism that maintains the large carbon reservoir in the deep ocean.
- **What limits phytoplankton growth?** – This slide presents a question that is the topic of many oceanographers research. It also gives one commonly accepted school of thought that most of phytoplankton growth is limited by nutrients. Part III of this module deals with the complexity of nutrient limitation and how it is connected to the biological pump in further details.
- **Sources of N, P, and Fe** – This slide is a super quick overview of the sources of the major limiting nutrients in the ocean. It is important to emphasize that

A good reading that could be inserted here for homework or class discussion is the recent review article by Falkowski called “The Power of Plankton.” 2012. Nature. **483**,S17-S20 (provided in lab packet)

**PART 2: GROUP PRESENTATIONS**

In this lab, groups of students will put together a short power point presentation and facebook profile page on a different marine organism. Groups of 2-4 would work well for this. Use all of the first 5 organisms, and if there is a larger class, use the optional additions.
Each of these organisms represents an important part of the biological pump. The teacher is not expected to be an expert on any of these organisms, so it is up to the groups of students to introduce the organisms to the class by presenting their own research. The will include an internet search (good websites to start at are provided in the student handout), using textbooks (a list of texts that can be used is provided and could be rented from a local university library), and one provided piece of primary literature or relevant review article.

Assign groups of 3-4 an organism and provide them with the appropriate primary literature article and the student handout (both provided). Each of these organisms is important and unique, so below is a very brief description of each of the organism. I suggest that after the groups have broken off and started the research, that the teacher visit each group and prompt the group to make sure that they understand the important information they should be conveying by using these talking points. The teacher should also be available as a resource for where to start looking (see provided list of appropriate resources), but it should be stressed that the students are to become the experts. Many of these articles will be vocabulary-heavy so use the glossaries in the books listed to help students understand the vocabulary. Important terms that students should introduce to the class within each organism group are listed below.

**LIST OF ORGANISMS/GROUPS**

- **Prochlorococcus**
  - *Prochlorococcus* is a genus of one of the smallest and most common photosynthetic organisms on earth. *Prochlorococcus* dominate in nutrient poor regions of the ocean.
  - Key words: cyanobacteria, picoplankton, oligotrophic.

- **Thalassiosira**
  - *Thalassiosira* is a genus of important photosynthetic eukaryotes called Diatoms. Diatoms dominate in nutrient rich areas of the ocean, but in addition to the N, P, and iron requirements, also require silica to make beautiful shells. Due to their rather large size, diatoms sink quickly and are often cited as important flux of the biological pump.
  - Key words: diatom, frustule

- **Trichodesmium**
  - *Trichodesmium* is a genus of cyanobacteria that can perform nitrogen fixation and photosynthesis. This provides an essential nutrient to areas of the ocean that otherwise have very little nitrogen. They have very high iron requirements.
  - Key words: Nitrogen fixation, diazotroph, colonial cyanobacteria
  - Primary literature: "Trichodesmuim, a Globally Significant Marine Cyanobacterium" by Capone, Zehr, Paerl, Bergman, and Carpenter in *Science*, 1997
  - Optional 2nd primary literature: "Marine nitrogen fixation: what's the fuss?" by Capone in *Current Opinion in Microbiology*, 2001

- **Planktonic Copepods**
  - Copepods are important zooplankton and voracious grazers of phytoplankton. Their fecal matter is especially dense and significantly contributes to sinking particles. Vertical migration also contributes to the biological pump.
  - Key words: zooplankton, vertical migration
  - Primary literature: pages 55-58 of "Upper Ocean Carbon Export and the Biological Pump" by Ducklow, Steinberg, and Buessler in *Oceanography*, 2001

- **Pelagibacter**
  - *Pelagibacter* is a genus of the globally important heterotrophic bacteria in the SAR11 clade. The SAR11 clade of organisms were not known until very recently, and they might be the most numerous bacteria on earth! They can thrive in low-nutrient waters and are important recyclers of organic carbon
  - Key words: heterotrophic bacteria, mesopelagic

- **Optional - Emiliania huxleyi**
  - *Emiliania huxleyi* is a species of important algae, coccolithophores. *Emiliania huxleyi* are calcifiers and can form huge blooms in the oceans and therefore cause large carbon export events.
  - Key words: phytoplankton bloom, calcifiers
  - Primary literature: “Emiliania huxleyi: bloom observations and the conditions that induce them.” By Toby Tyrrell and Agostino Merico

- **Optional - Roseobacter**
- *Roseobacter* is a genus of heterotrophic bacteria in the ocean and our example of very important particle associated bacteria.

- Keywords: heterotrophic bacteria, marine snow, particle associated


**Optional – Planktonic Salps**

- Salps are zooplankton that filter feed on phytoplankton (and whatever else may be in its path). They respond very quickly to blooms and their death result in sticky substance which can sink, significantly contributing to marine snow.

- Keywords: filter feeder, marine snow

- Primary literature: pages 55-58 of “Upper Ocean Carbon Export and the Biological Pump” by Ducklow, Steinberg, and Buessler in *Oceanography*, 2001

After an appropriate amount of time working on the presentations, students should present each organism as a group and handing out their facebook page as a resource for the other students. Each student will end up with a packet of facebook pages for each organism and can take notes on these.

**PART 3: CLASS SYNTHESIS**

The final part of this module is to have a class discussion about the interconnectivity of their organisms and to understand how each of the groups’ organisms fit into the biological pump by connecting them in a “carbon web.” This idea will be familiar to the students who have made food webs in introductory biology courses. The figure is based off of the figure from Part I on the final overview of the biological pump slide, from Z. Johnson in the Nature Magazine.

First I would encourage each group to come up with a simple way to draw each of the organisms and to define each drawing on the board. Having different colors would be helpful (little green = Prochlorococcus, little blue = heterotrophic bacteria). As you go farther along, define other symbols (flow of carbon, sinking organic material).

Encourage students to use colored pencils or different colored pens and provide blank sheets of paper to take notes and create their own drawing. Alternatively, I have provided a very simple power point that goes through these steps instead of drawing them on the board.

Draw on the board a schematic of the ocean with the surface ocean, deep ocean, and sea floor. Stress that only CO$_2$ in the surface ocean is in equilibrium to the atmosphere. Probe the class to identify which of the presented species are phytoplankton. Add the phytoplankton – Prochlorococcus, Thalassiosira, Trichodesmium, and Emiliania huxleyi – to the surface ocean. They live only in the surface ocean because they require light to survive.

Next add grazers to the surface ocean (those who eat phytoplankton, copepods and salps). They are in the surface ocean because their food (phytoplankton) are in the surface ocean.

Now add sinking organic material throughout the water column. Brainstorm different sources of sinking organic material in this small system

- Fecal pellets from grazers
- Death of a large phytoplankton bloom
- Dead grazers
- “Messy” feeding by grazers resulting in sinking “crumbs” of their food

Add heterotrophic bacteria to surface and deep ocean. *Roseobacter* should be particle associated, pelagiabacter can be on or off particles.

Add direction of CO$_2$ to or from each depicted organism/group of organisms. Which are the organisms that respire (give off carbon) and which are the ones that photosynthesize (consume carbon)? Overall, you should have net photosynthesis in the upper ocean and net respiration in the deep ocean.

Quantifying the biological pump is an active area of research in oceanography. Probe the students to understand why.

- Why is the biological pump important? *Pumps CO$_2$ from the surface ocean to the deep ocean*
Would the atmospheric CO\textsubscript{2} be different if the biological pump didn't exist? Yes!!!!! The CO\textsubscript{2} of the atmosphere would be much higher than current if there was no biological pump.

How does the biological pump affect climate? Lowers atmospheric CO\textsubscript{2} and therefore decreases the greenhouse gas effect.

Using our small-system example of organisms, discuss the interconnectivity of the different organisms

- **What limits the growth of each type of phytoplankton?**
  - *Tricho* – generally thought to be iron or phosphorus limited since it can fix its own nitrogen
  - *Thaps* – could be limited by N, P, Fe or Si (to grow shells)
  - *Prochlorococcus* - could be limited by N, P, Fe (but can survive at much lower concentrations than other phytoplankton), can’t survive well in cold environments
  - *Ehux* – could be limited by N, P, or Fe, doesn’t survive well in warm environments

- **What limits the growth of the grazers?**
  - Both copepods and salps are limited by their food source, phytoplankton (and oxygen)

- **What limits the growth of the heterotrophic bacterias?**
  - Both types of heterotrophic bacteria are limited by their food supply, decaying organic matter (and oxygen)

- **What if there were no phytoplankton?** What would happen to this food web and the biological pump of our system?
  - It would collapse! No phytoplankton = no food for grazers = no food for heterotrophs = no biological pump!!

- **What if there were no grazers?** What would happen to this food web and the biological pump of our system?
  - No grazers = much less respiration in the upper ocean. Bacteria would only feed on decaying phytoplankton material and no fecal matter. This would lead to a much more efficient biological pump, less atmospheric CO\textsubscript{2}, cooler planet!

- **What if one or more species/groups of species were affected by a viral attack?**
  - Depending on the species/group of species affected, this could increase or decrease the biological pump’s strength.

A lot of research is being put into predicting how the biological pump will change with global climate change. Discuss possible scenarios of both ocean acidification and increased stratification and how they could change the biological pump. Please note that there really is no consensus on this yet scientifically as there are many

- **Ocean Acidification**
  - Could effect the ability for coccoliths to grow and affect blooms, decreasing strength of bio pump (because they grow calcium carbonate shells)
  - Could effect nitrogen fixation by Trichodesmium (quite a bit of literature on this) – increasing N\textsubscript{2} fixation could increase strength of bio pump, decreasing N\textsubscript{2} fixation could decrease strength of bio pump.
  - Could have physiological affects on higher trophic levels

- **Increased stratification leading to less mixing nutrients**
  - Especially affecting diatoms (who thrive in nutrient-rich areas and require the extra nutrient of silica), could decrease bio pump
  - Overall the phytoplankton would be under nutrient limitation moreso than now – decreasing the biological pump

If students have other ideas of what could change the biological pump – open the floor to them.

POST SURVEY: Please have each student fill out the Post Lab Survey and mail both surveys to:

Katherine Heal, School of Oceanography, Box 355351, University of Washington, Seattle WA 98195, kheal@uw.edu
Your assignment is to become an expert on a globally important marine organism. You will use provided resources to answer the following questions about your organism. You will then make and present a power point that will answer these questions and provide background on your organism for your peers. Finally, you will create a facebook profile for your organism for distribution that will synthesize what you have learned about your organism. Use the provided template for your facebook page, but feel free to get creative. If you want to add a category or something doesn't make sense with your organism, change the template, not all organisms are created equal!

QUESTIONS TO ADDRESS IN PRESENTATION AND (IF APPLICABLE) ON FB PROFILE

1. What type of organism is it?
2. What do they look like? How big are they? How common are they?
3. Where are they located in the ocean?
4. What do these organisms eat/need to survive?
5. What are some other important or interesting facts about this organism?
6. How is this organism related to the biological pump?

RESOURCES

1. Your teacher will provide a piece of primary literature that will provide answers to many of these questions – remember that these are written by scientists who study these organisms everyday so they will probably be very scientific, don’t be discouraged.
2. Your teacher will also have a number of textbooks available for
3. Wikipedia is a great place to start – follow the information you find here to citations
4. Microbewiki is wiki created for microbes (and their fans) – some of your organisms will have information here
Pre Module Survey

Please fill out this survey to help improve the lab. This survey is anonymous and will NOT influence your grades. It is OK to guess the correct answer. The information you provide will help science educators understand if this lab is effective.

1. **How are photosynthesis and respiration related to CO\(_2\)? Circle one.**
   a. Photosynthesis and respiration produce CO\(_2\)
   b. Photosynthesis produces CO\(_2\), respiration consumes CO\(_2\)
   c. Photosynthesis consumes CO\(_2\), respiration produces CO\(_2\)
   d. Photosynthesis and respiration consume CO\(_2\)

2. **Where does most of the earth’s photosynthesis occur? Circle one.**
   a. Forests
   b. Oceans
   c. Plains/grasslands
   d. Lakes and rivers

3. **Please tell us how much do you know about the following topics.**

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4. **What was your organism? How is it related to the biological pump?**

5. **What is another organism that you learned about (don’t worry about spelling!). How is it related to the biological pump?**