Marine Microbiology in the Oligotrophic Ocean

SMILE High School Teacher Workshop
Giovannoni Lab
August 5th, 2019
Expected Learning Outcomes

- The ocean is the largest biome on Earth and it is full of life.
- Microorganisms are the most abundant and important inhabitants of the ocean.
- Microbes are diverse (size, shape, and function)
- Microbes form ecosystems where their interactions impact global processes, including the carbon cycle.
- We can use models to study and conduct experiments on global processes such as the carbon cycle.
Outline of Lesson

- Marine Microbiology and Carbon Cycle introduction presentation
- Expert Groups
- Modeling presentation
- Explain *Oligotrophic* Simulation
- *Oligotrophic* Simulation 1, 2, and 3
- Conclusions
Is the Earth BLUE or GREEN?
70% of the Earth’s surface is ocean

The ocean is on average 4000m deep

The majority of the ocean is oligotrophic

Every drop of the ocean contains life!
What types of organisms live in the ocean?

Which types are most important to our planet?
Marine Bacteria

Image from Yanlin Zhao and Stephen Giovannoni
Seawater filtered on 0.1µm filter
Fun Fact:
In 1 drop of seawater there are 1 million bacteria!
Marine Microbial Vocab!

Oligotrophic: an area of the ocean with low nutrient concentrations

Phytoplankton:
- Create biomass from the sun (like plants)
- example: Prochlorococcus

Bacterioplankton:
- Use biomass produced by phytoplankton to survive
- example: SAR11

Zooplankton:
- Consume both phytoplankton and bacterioplankton
- example: copepod
SAR11 is the most abundant bacterioplankton

Discovered in the Giovannoni Lab at OSU
Prochlorococcus is an important phytoplankton.

200 in a row = 1 human hair!
Marine microbes are small and diverse

Fig. 2. A comparison of the size range (maximum linear dimension) of phytoplankton relative to macroscopic objects.

Finkel et al., 2010
What are these marine microbes doing?

Why should we care about them?
50% of all oxygen we breathe is produced by microbes in the ocean!!
Photosynthesis by phytoplankton removes CO$_2$ from the atmosphere, and forms biomass and O$_2$.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$
Respiration by heterotrophs uses biomass and O\textsubscript{2}, producing CO\textsubscript{2}

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} \]
How is Oxygen produced if photosynthesis and respiration are balanced?

\[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \]

\[ 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \]
The Carbon Cycle

[Diagram showing the carbon cycle with various components such as phytoplankton, zooplankton, microzooplankton, bacteria, and organic carbon. The cycle involves the transfer of carbon between the atmosphere and the deep oceans.]

Phytoplankton are the engine of the 'biological pump' (Fig. 1) that helps maintain a steep gradient of CO₂ between the atmosphere and the deep oceans where 38% of the atmospheric CO₂ is stored. The net result of the carbon cycle is the transport of CO₂ from the atmosphere to the deep ocean, where it stays, on average, for roughly 200 years. This process is referred to as the 'biological pump.'

The history of plant and animal introduction into new areas can have significant implications for genetic diversity. The introduction of foreign genes into these populations can result in changes to the genetic constitution of the species. The introduction of exotic species can affect the local gene pool, potentially altering the genetic diversity and evolution of the native species.

The effects of genetic distance have been studied in various species, including the deerweed (Lotus scoparius). In this species, the geographical distance from which introgression occurred was estimated to be between 8% and 20% of the species' range. These findings have broader implications for the study of genetic diversity and the management of natural populations.

In an experiment involving 12 populations of a shrub species, there was only weak correlation between geographical and genetic distances. This suggests that the genetic constitution of the species is often patchy on a local scale and may be influenced by other factors such as local adaptation and isolation.

The merits of introducing exotic species into new areas can vary with the type of organism involved. In some cases, the introduction of outbreeding species, such as birch and poplar, might also restrict the distances over which pollination is possible. However, self-pollinating species, such as corncockle, can often self-pollinate, which may reduce the genetic diversity in these populations.

The relationship between geographical and genetic distances is often seen as inverse, with closer relationships correlating to greater genetic similarity. However, this inverse relationship may not always correspond to the actual distances. For example, in a study of deerweed, the spatial variability in the genetic constitution was found to be much lower than expected, suggesting that the genetic diversity of this species is not as strongly influenced by geographical distance as previously thought.

In conclusion, the introduction of exotic species into new areas can have both positive and negative impacts on the genetic diversity and evolution of native species. Understanding the genetic and ecological implications of such introductions is crucial for effective conservation strategies and the management of natural populations.
The Carbon Pump sequesters some fixed carbon, allowing net $O_2$ production and $CO_2$ removal.
Marine Microbial Interactions control the strength of the Carbon Pump!
Why is there so much more 
$O_2$ in the atmosphere than 
$CO_2$?

Where do fossil fuels come from?

How is all of this related to 
global climate change?
The Great Oxidation Event

- Oxygen begins to appear in the atmosphere
- Oxygen-producing bacteria get their start
- Methanogens begin making major contributions to the atmosphere
- First microscopic life begins consuming carbon dioxide
- High carbon dioxide compensates for the faint, young sun

Relative Concentration

Time (billions of years ago)
Effect of plate tectonics - productive areas in the tropics and shallow seas
Mass carbon burial hypotheses

- This hypothesizes the locking up of more organic matter in sediments before they had a chance to decay.

- Prevalence of shallow seas in the Carboniferous Period

- Geological viewpoint – production of clays able to absorb organic matter and preserve it between the seafloor and the assembly of a supercontinent whose weathering could stimulate ocean life by adding nutrients.

- Biological viewpoint - arrival of lichens on land (also increasing weathering and the levels of nutrients in the ocean).
Shallow seas mean sinking carbon is buried faster, so less is respired during the sinking process.

Over 100s of million years, buried carbon becomes fossil fuels!
Burning fossil fuels releases CO$_2$ from buried carbon, causing Atmospheric CO$_2$ Concentrations to Increase
Burning Buried Sunshine

Today’s average US gallon of gasoline requires approximately 90 metric tons of ancient plant matter as precursor material.
What are these marine microbes doing?

Why should we care about them?
The Carbon Cycle

The 'biological pump' is a collective property of a complex phytoplankton-based food web. Phytoplankton are the engine of the 'biological pump', which transports carbon from the atmosphere to the deep ocean, where it stays, on average, for roughly 1,000 years. The food web's structure and the relative abundance of species influence how much CO$_2$ is stored. Using sunlight for energy and dissolved inorganic nutrients, phytoplankton convert CO$_2$ to organic carbon, which forms the base of the marine food web. As the carbon passes through the food web, it is remineralized back to CO$_2$, and this cycle continues.

This diagram illustrates the flow of carbon through the ocean, showing the role of phytoplankton in the 'biological pump'. The diagram includes various components such as large and small phytoplankton, zooplankton, microzooplankton, and bacteria, all of which play crucial roles in the carbon cycle. The diagram also highlights the importance of ventilation (upwelling) and deep water formation in maintaining the sharp gradient of CO$_2$ between the atmosphere and the deep oceans.
The Carbon Cycle

The ocean is a carbon sink.

Marine microbes control how much carbon is absorbed in the ocean.

Understanding these microbial processes may be the key to understanding (and potentially mitigating) global climate change.

Chisholm *Nature* 2000
Marine Microbe and Carbon Cycle Expert Groups

**Abiotic**
These are chemicals and processed that can be turned into biomass.

**Phototrophs**
These are organisms that use photosynthesis to turn atmospheric carbon into their biomass.

**Heterotrophs**
These are organisms that get energy by consuming biomass; it can be from debris or other organisms.

**Viruses**
These are non-living entities that use living organisms to make more copies of themselves!
How can we experiment with marine microbial ecology and the carbon cycle in the classroom?
How can we study racecars in the classroom?
Models can be used to study systems
Models use data to recreate actual systems
Models can be used to study the ocean!
How does this relate to wind-pollinated, flowering plants? NATURE and its response to climate might also restrict the distances over which information is likely to be patchy on a local scale. (or both): geographical proximity of a seed analysis of genetic or ecological similarity similar situations. So the introduction of it is that the individual will survive well in the closer the relationship is, the more likely inverse relationship to genetic distance. The cumulative fitness of plants showed an interaction between geographical and genetic dis- infections is often seen as a way of increasing populations, there was only weak correla- habitats. In an experiment involving 12 organisms ranging from butterflies to birds being found in both arid and well-watered that there is little evidence of local genetic genetic diversity, and has been attempted in introductions were estimated to be between 8% and produce effectively fit — that is, less able to survive and repro- weed populations is likely to make them less rapid gene flow and little opportunity for local isolation and adaptation. In such rapid dispersal from a given area, outbreeding species, one could argue, the for local isolation and adaptation. In such production of large genes from distant populations is almost half of the photosynthesis on 1,000 years. The food web's structure and the relative abundance of species influences how much CO production of genes between populations suggests that was generally higher in the first generation and these tiny cells play a huge in the sea. So these tiny cells play a huge consumers in surface waters, most of it is converted back to CO will be pumped to the deep ocean. This structure is dictated largely by the availability of inorganic CO maintains a steep gradient of CO together with the 'solubility pump' (right), which is driven by chemical and physical processes, it
Scientists use data to build models of marine ecosystems.
Microbial Ecology Model

Oligotrophic
How are the diverse marine microbes interacting in the environment?
How do microbial interactions move biomass between groups of organisms?
How to play: Oligotrophic
Set up

Give 20 cubes to each player of a single color

Pull out the sunlight

Shuffle all of the other cards together
Set up

Give each player 3 cards
Set up

Put the sunlight card in the center of the play area

You are now ready to play!
How to play:

Each turn, play 1 card from your hand so it connects to at least one other card. Put cubes of your color equal to the number on the card. If you play a Phototroph by the sun, add 2 more cubes.
When you play a card:

The arrow points to the cards that it effects.

**Take:** Switch the cubes to your color and move it to your card.  
(Remember some can only take from certain others!)

**Return:** Give the cubes on the indicated card back to their player.
To win, start your turn with 5 or less biomass (cubes).
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Oligotrophic is a fast-to-learn, strategic tile placement game where players compete to place biomass the fastest. In the game players will select and play hexagonal cards based on actual microorganisms to accumulate biomass, often getting bonuses, hurting, or taking biomass from the other organisms they encounter.

Use it as a fun way to teach about the ecology of globally significant marine microorganism!

Available for download: https://microbiology.science.oregonstate.edu/smile-workshops