Science Lesson Plan:

Interactive Biogeochemical Cycle

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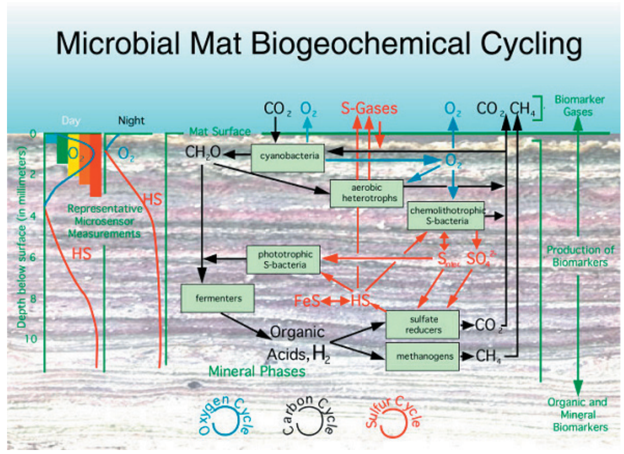
Background

As Earth's earliest ecosystems, microbial mats have had over three billion years to evolve into the complex ecosystems that we see today. The metabolic processes of the organisms in microbial mats are controlled by environmental conditions, but the products of metabolism also change the environment experienced by the microbes. The result is a cycle in which the microbes both control, and are controlled by, their own environment. In this activity, students produce a skit in which the activities of some microbial mats microbes, as well as their interaction with the environment, are highlighted.



A few representative pathways in the cycling of carbon, oxygen and sulfur in a microbial mat. Figure modified after a figure by Fenchel, T., and B. J. Findlay. 1995. Ecology and Evolution in Anoxic Worlds. Oxford University Press.

Main Concept

Microbial mats are entire ecosystems where different organisms perform different roles (producer, consumer, decomposer) in the ecosystem. The position that an organism occupies in a mat is predictive of its role in the ecosystem. Whether it uses or provides oxygen will be a clue to its position and biogeochemical functions.

Scientific Question

What are the functions of different bacteria in a microbial mat?

Objectives

1. The student will gain a basic understanding of several of the biogeochemical processes in microbial mats.
2. The student will understand the different roles of organisms in a microbial mat ecosystem.
3. The student will gain an understanding of how microbial mat ecosystems contributed to the Earth's biosphere.

Abstract of Lesson

Students will act out the biogeochemical cycles in a microbial mat using the script below. Basic metabolic and chemical processes are explained in the activity.

Prerequisite Concepts

1. Cyanobacteria are a group of bacteria that perform oxygen-producing photosynthesis.
2. Bacterial cell structure is different from other organisms. Bacteria are prokaryotic organisms and as such, have no membrane-bound nucleus.

Misconceptions

1. Charts and flow diagrams that explain biogeochemical cycles may confuse students.
2. Students may define ecological concepts, such as community and competition between organisms, based on everyday experiences rather than scientific understanding.
3. Students may believe that adaptation means that organisms deliberately adapt to environmental changes.[1]

Major Concepts

1. Cyanobacteria are the primary producers in a microbial mat ecosystem.
2. Producers, consumers and decomposers cycle chemical compounds containing energy in a mat ecosystem to sustain life.
3. Mat organisms respond to changes in chemicals and light in a mat and (some, not all) position themselves to best use available resources.
4. The major source of energy in many mat ecosystems is sunlight. In others, such as those that occur at deep-sea vents, it can be the energy contained in chemical compounds.
5. Sunlight is transferred by cyanobacteria and other producers into chemical energy through photosynthesis.
6. Energy passes from organism to organism in food webs as chemical compounds containing energy.
7. Predation and lack of light, water and other chemical resources limit the growth of a microbial mat.
8. Microbial mats organisms have avoided predation by adapting to life in extreme conditions including heat, cold, hypersaline conditions, etc.
9. The atmosphere of early earth was created through the activities of microbes that contributed oxygen and other gases.

National Education Standards

Fully Met	Partially Met	Addressed
NSES C6(5-8): Regulation and Behavior b **NSES C7(5-8):** Populations and Ecosystems a, b, c, d	**NSES B6(5-8):** Transfer of Energy a, f **NSES C4(5-8):** Structure and Function in Living Systems a, b **NSES C6(5-8):** Regulation and Behavior a, c, d **NSES D4(5-8):** Structure of the Earth System k	**NSES B6(5-8):** Transfer of Energy d **NSES C4(5-8):** Structure and Function in Living Systems c
	2061: 5A(6-8) #1 **2061: 5E(6-8) #1, #2, #3** **2061: 11A(6-8) #2**	**2061: 4E(6-8) #2** **2061: 5A(6-8) #5** **2061: 5D(6-8) #1, #2**

California Science Standards

Fully Met	Partially Met	Addressed
Grade 6: Ecology#5 a, b, c, e	Grade 8: Chemistry of Living Systems #6 b	Grade 7: Evolution #3 a Grade 7: Earth and Life History #4 a, g Grade 8: Chemistry of Living Systems #6 a

[1]National Science Education Standards, p. 7 http://www.nap.edu/readingroom/books/nses/html/6d.

Reading on Topic related to study:

Microbes@NASA Web Site http://microbes.arc.nasa.gov/

Materials List

1. Different cards (81/2 by 11 or larger) labeled to represent different elements and compounds in the mat (available as a PDF file)
   - Oxygen
   - Carbon Dioxide
   - Acetate
   - Sulfuric Acid
   - Hydrogen Sulfide
   - Water
   - Organic Matter (Sugars)
   - Sulfur
   - Methane
   - Hydrogen
   - Alcohol
   - Organic Acids
2. Labeled pictures of organisms found in the mat (*Gloecapsa* (cyanobacteria), Oscillatoria (cyanobacteria), *Spirulina* (cyanobacteria), unicellular cyanobacteria, diatoms, *Phormidium* (cyanobacteria), sulfur bacteria, purple sulfur bacteria, colorless sulfur bacteria, fermenters, and *Microcoleus* (cyanobacteria)) drawn by students on day one. A teacher can print pictures of *Gloecapsa*, *Spirulina*, unicellular cyanobacteria, diatoms, *Phormidium*, sulfur bacteria, purple sulfur bacteria, colorless sulfur bacteria, fermenters, and *Microcoleus* from the Life in a Microbial Mat hand-out if student drawings are not available.
3. Large cards labeled: "Producers", "Consumers" and "Decomposers"
4. Cards labeled with: "Fish", "Crab", and "Nematode"
5. Script for activity
6. *Stromatolite Explorer* movie from Microbes @ NASA web site http://microbes.arc.nasa.gov/

Preparation

1. Label cards as outlined above.
2. Collect student drawings or prepare pictures as described above.
3. Make enough copies of the script for the students.
4. Download *Stromatolite Explorer* movie from the Microbes @ NASA website http://microbes.arc.nasa.gov/

Engage

1. Explain that students are continuing the unit on microbial mats. The bacteria that they observed yesterday are members of microbial mat ecosystems. The bacteria and other microbes form a thick layer of biomass and conduct many of the processes necessary to control our planet. As a community, the bacteria produce different materials that are needed by other members of the mat community and other organisms to survive.
2. Show the *Stromatolite Explorer* Clip to introduce students to a microbial mat. A teacher's guide is available on the Microbes @ NASA website http://microbes.arc.nasa.gov/.
3. Explain that students are continuing the unit on microbial mats. The bacteria that they observed yesterday are members of microbial mat ecosystems. The bacteria and other microbes form a thick layer of biomass and conduct many of the processes necessary to control our planet. As a community, the bacteria produce different materials that are needed by other members of the mat community and other organisms to survive.

Interactive Biogeochemical Cycle Script

Roles:

Narrator 1
Narrator 2
Diatom
Cyanobacteria:
- ***Gloecapsa,***
- ***Oscillatoria,***
- ***Spirulina,***
- **Unicellular Cyanobacteria,**
- ***Phormidium***
- ***Microcoleus***

Aerobic Heterotrophs
Fermenter 1
Fermenter 2
Sulfate Reducer 1
Sulfate Reducer 2
Colorless Sulfur Bacteria 1
Colorless Sulfur Bacteria 2
Purple Sulfur Bacteria
Methanogens

How do Microbial Mats work?

NARRATOR 1:

All life forms require energy to grow and reproduce, and that energy must somehow be extracted from the environment. Humans, for example, breathe air and eat food. When the organic matter in the food combines chemically with the oxygen in the air, energy is released. Where did the oxygen and the organic matter come from? Both were made by other organisms, so that our survival is dependent upon the activity of other life forms.

NARRATOR 2:

Microbial mats function in the same way as a complex food web in which each organism both depends and is depended on by other members of the community, but this community is only a few millimeters deep. The organisms that live in microbial mats utilize an amazing array of energy harvesting strategies.

NARRATOR 1:

Microbes use sunlight and harvest energy by conducting photosynthesis. Chemical processes are other ways that some mat organisms extract energy. Some microbes use respiration to release energy from organic matter.

NARRATOR 1:

Let us look at the top of the mat.

DIATOM:

I am a diatom and I am a single-celled organism found at the top of a mat. I produce oxygen.

[Cyanobacteria (Gloecapsa, Oscillatoria, Spirulina, unicellular cyanobacteria, Microcoleus) come to the front of the room]

UNICELLULAR CYANOBACTERIA:

We are the primary producers of the microbial mats and the basis of the food web in this ecosystem.

MICROCOLEUS:

We harvest the energy contained in sunlight and turn it into food such as sugars and organic matter.

PHORMIDIUM:

This uses the same process of photosynthesis found in higher plants.

OSCILLATORIA:

We take carbon dioxide and water [Displays 10 carbon dioxide and 10 water cards]…

GLEOCAPSA:

to make food [Displays one organic matter (sugar) card]…

SPIRULINA

and release oxygen. [Displays oxygen card]

[All cyanobacteria take water and carbon dioxide cards and exchange them for oxygen and organic matter (sugars) cards.]

NARRATOR 2:

Those sugars are not really found just as sugar (like sugar cubes) but with some other stuff, too. So, what is really being produced is “organic matter”. The next layer of the mat is composed of aerobic heterotrophs that use the sugar and oxygen produced by the cyanobacteria. Not all of this organic matter is used by the cyanobacteria, some is transferred to the rest of the mat.

[Cyanobacteria pass the organic matter (sugars) and oxygen to the Aerobic Heterotrophs]

AEROBIC HETEROTROPHS:

We use a process called aerobic respiration to break down the sugar organic matter produced by the cyanobacteria with the oxygen produced by the cyanobacteria. We make carbon dioxide and water during this process. We work mostly during the day, since this is when oxygen is produced through photosynthesis. At night, we run out of oxygen. The carbon dioxide and water that we produce can be reused by the cyanobacteria during photosynthesis.

[Passes carbon dioxide and water cards back to the cyanobacteria.]

NARRATOR 1:

Most of the carbon dioxide produced by the aerobic heterotrophs is used by the cyanobacteria, but some of this gas leaves the mat and may be used by other organisms or enters our atmosphere.

CYANOBACTERIA (ALL IN UNISON):

This is only part of one of the cycles in the mat. Other organisms also use the sugar and organic matter that we produce. *[Passes the organic matter (sugars) card to the fermenters.]*

NARRATOR 2:

However, they have other ways of surviving based on compounds produced by other members of the mat community.

FERMENTER 1:

We are the fermenters. While we do not completely break down the sugar, we do transform it to alcohol, organic acids, hydrogen and carbon dioxide that are used by other organisms in the community.

FERMENTER 2:

We work as decomposers in the mat ecosystem. *[Passes the organic acids and hydrogen cards to the sulfate reducers and the methanogens.]*

NARRATOR 1:

Did you know that some cyanobacteria act as fermenters at night?

NARRATOR 2:

Yes, when cyanobacteria lack light and oxygen, they can still be busy working as fermenters.

NARRATOR 1:

Now we are entering a deeper level of the mat that does not contain oxygen. This is where sulfate reducing bacteria are found.

SULFATE REDUCER 1:

[Takes the organic acids card and the hydrogen card.] We can respire chemicals other than oxygen to survive.

NARRATOR 2:

The position of these sulfate reducers can change in a mat depending on the level of oxygen. At night, oxygen does not penetrate as deep in the mat, so there are more areas where sulfate reducers can operate.

SULFATE REDUCER 2:

We use sulfate and carbon dioxide in a process called anaerobic respiration. There are other bacteria that can also use iron, manganese and nitrate, but we actually get most of the work because there is a lot more sulfate than there is of these other things. We use sulfate to "burn" organic matter by anaerobic respiration and can consume one-third of all organic carbon. We consume organic matter in mats and we often leave the mat smelling like rotten eggs from the hydrogen sulfide that we make. We work as decomposers in the mat ecosystem. *[Displays the carbon dioxide card, hydrogen sulfide card, and the water card.]* *[Passes the carbon dioxide and water cards to the cyanobacteria.]*

CYANOBACTERIA: *[All cyanobacteria hold up the carbon dioxide and water cards.]* The carbon dioxide and water allow us to continue producing organic matter (sugars) and oxygen and the organic matter (sugars) and oxygen we don't use becomes available for the rest of the community.

COLORLESS SULFUR BACTERIA 1:

We are colorless sulfur bacteria and are a type of chemolithotrophic sulfur bacteria. We use the energy contained in the gradient between reduced sulfur compounds (produced by sulfate reduction), and oxygen (produced by the cyanobacteria) like a battery. *[Holds up hydrogen sulfide card and oxygen card.]* Using this redox gradient, we are able to synthesize organic matter.

COLORLESS SULFUR BACTERIA2:

We are among the most motile of the microbes in the mat because we need to locate precisely at this redox gradient. This gradient is deep in the mat during the day due to oxygen production by cyanobacterial photosynthesis, but can move to the surface at night after all available oxygen has been consumed through aerobic respiration. We use the energy that is contained in the gradient between oxygen and sulfide like a battery to make our own sugars from carbon dioxide.

NARRATOR 1:

Many of the organisms in the lower areas of the mat do not receive enough light to conduct photosynthesis. Since infrared radiation penetrates deeper than light, there is another kind of photosynthesis that can take place.

PURPLE SULFUR BACTERIA 1:

We are purple sulfur bacteria and are a type of phototropic sulfur bacteria. We do not live at the top of the mat and get all of the light needed for photosynthesis. Light at the top of the mat is used by cyanobacteria. Light is also scattered by sand and sediment. The light needed for cyanobacterial photosynthesis only penetrates a few millimeters into microbial mats. However, infrared radiation, like the heat "waves" in a heat lamp, penetrates deeper.

PURPLE SULFUR BACTERIA 2:

We use infrared radiation and the hydrogen sulfide produced by the sulfate reducing bacteria to perform a type of photosynthesis called anoxygenic photosynthesis. This type of photosynthesis does not generate oxygen. Through this process, we are able to fix carbon dioxide into simple sugars in a process similar to that used by the cyanobacteria. Fermenters use the sugars that we produce. *[Holds up (organic matter (sugars) card.]* We also produce acid. [Holds up sulfuric acid card.]

METHANOGENS:

[Holds up the organic acid card and the acetate cards.] We are the methanogens and produce methane from acetate and hydrogen that is generated by fermentation. This process yields little energy and is the "last resort" for microbes in the mat. [Holds up the methane card. The methane card should be left at the top of the mat.]

NARRATOR 2:

Even though may of the gases and elements are used in the mat, some are produced in greater quantities than are needed in the mat.

NARRATOR 1:

Gases that are not used leave the surface of the mat. This is how oxygen and other gases originated in earth's atmosphere.

[At this time, organisms bring up the gases they produce. Cyanobacteria bring oxygen, colorless sulfur bacteria bring carbon dioxide and sulfur gases, sulfate reducers bring carbon dioxide, and methanogens bring methane.]

[Narrator 1 collects the gases.]

NARRATOR 2:

A microbial mat is a productive community with organisms that depend on each other for survival. The number of organisms living in a microbial mat depends on the resources the community has available. The community depends on light, water, chemicals and temperature in order to grow. Predators will limit the survival of a microbial mat.

NARRATOR 1:

In fact, microbial mats flourished 3.5 billion years ago. It wasn't until animals evolved and started consuming microbial mats that communities of mats became less common on earth.

CYANOBACTERIA, SULFATE REDUCING BACTERIA, COLORLESS SULFUR BACTERIA, PURPLE SULFUR BACTERIA, AND METHANOGENS (all in unison):

We may not cover the planet today, but we were able to survive.

COLORLESS SULFUR BACTERIA:

Mat organisms evolved to survive in places where many fish and animals that consume us cannot live.

SULFATE REDUCING BACTERIA:

Mats evolved to live in hot springs…

PURPLE SULFUR BACTERIA:

hypersaline ponds, lakes, marshes, and oceans…

METHANOGENS:

within rocks, sand, and other environments where predators are not.

CYANOBACTERIA:

Those animals just changed our lives.

PHORMIDIUM:

Instead of making food, like I do, the animals are consumers that obtain food by eating other organisms.

OSCILLATORIA:

That microscopic worm, or nematode, is just one example of organisms that try to eat us.

SPIRULINA:

If something or someone, punctures the surface of the mat, the edges are just enough for us to become fish food. The fish get their jaws around the mat, and we are gone.

DIATOM:

Watch out! It looks like crabs have found us in the intertidal zone. We are being invaded by predators.

END

Learning Check Activity

1. Label different sections of the room: Producer, Consumer and Decomposer.
2. Pass out cards labeled with different microorganisms and categories of microorganisms in the mat (cyanobacteria (*Gleocapsa, Oscillatoria, Spirulina*, unicellular cyanobacteria, *Microcoleus*), fermenter, sulfate reducing bacteria, colorless sulfur bacteria, purple sulfur bacteria, diatoms) as well as some consumers (fish, crabs, nematodes).
3. Have students move to the section of the room that correctly categorizes the organism.

Answers

Producers	Decomposers	Consumers
Cyanobacteria (*Gleocapsa, Oscillatoria, Spirulina*, unicellular cyanobacteria, *Microcoleus*), diatoms, purple sulfur bacteria, colorless sulfur bacteria, methanogens	sulfate reducing bacteria, fermenters, aerobic heterotrophs, methanogens	fish, crabs, nematodes

Follow-up: The Microbial Mat Biogeochemical Cycling Diagram from the Microbes @ NASA website http://microbes.arc.nasa.gov/ may be used to reinforce concepts.

Credits

Lesson Plan:

Art, Graphic Design & Layout: C. Triano & T. Esposito, TopSpin Design Works