Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2010 Volume III: Geomicrobiology: How Microbes Shape Our Planet

Ecosystems Beneath the Surface

Curriculum Unit 10.03.04
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Introduction

In the curriculum unit, Ecosystems Beneath the Surface, students will develop an understanding of ecosystems that exist in a dimension not in view to the naked eye and that this dimension exists in the microbial world found in communities called microbial mats. Students will gain insight into microorganisms that rely on the sun for energy, and other microorganisms, in particular, prokaryotic bacteria and archaea that can harness energy from other inorganic sources. These diverse species help to recycle minerals necessary to support life on Earth.

They will examine microscopic organisms found in the salt marshes of the Long Island Sound, in particular, purple microbial mats that are considered to be "layered communities." They will discover the interdependence and recycling of these organisms through the sulfur cycle. Through hands-on activities, students will be given the opportunity to distinguish between the different layers of the mat and see how each layer depends on the other layers for survival.

This unit will be taught to four sixth grade general science classes at Betsy Ross Arts Magnet School in New Haven, CT. Science is departmentalized at Betsy Ross and each class period is fifty-two minutes long. The sixth grade curriculum has four science standards that must be taught throughout the year and these are: Ecosystems, Simple Machines, How Human Activities Affect Our Waters, and Weather. Two of the standards, Ecosystems and How Human Activities Affect Our Waters, will be directly enhanced through teaching this unit.

Students will engage in several activities that will take a series of months to complete and this fits into the sixth grade curriculum since three of the four units overlap and are not exclusive of one another and those units are Ecosystems, Weather, and How Human Activities Affect Our Waters. All three of these units discuss the water cycle and how/that life on Earth cannot exist without water, even in the microbial world. Connecticut has instituted embedded task performances (see Appendix) and the sixth grade embedded task entitled "Dig In" deals with properties of soil. Implementing this unit on microbial mats will compliment the embedded task.

Background Information

All life forms require energy in order to carry out life functions such as eating, breathing, reproduction and growth. This energy comes from the surrounding environment. Life forms would not exist without the existence of microorganisms. The oxygen that humans need would not be here if not for the cyanobacteria that exist in microbial mats. Life exists in three domains: eukarya, bacteria, and archaea. The eukaryotes include organisms such as fungi, animals, and plants. Then there are bacteria and archaea which make up most of the microorganisms and are both prokaryotes--single-celled organisms without a nucleus or many other organelles. The major difference between bacteria and archaea is, not in their physical appearance or morphology, but in their DNA sequences. Bacteria and archaea are similar in that both are prokaryotes which mean they do not have DNA enclosed in a membrane-bound nucleus whereas eukarya do.

Since all life forms require energy in order to carry out life functions, energy and electron flow are used interchangeably. Energy, on a chemical/cellular level, is referred to as electrons, which are part of all atoms that make up matter. Organisms need an electron source and an electron sink in order for electrons to flow. Organisms need this electron flow in order to produce ATP. ATP is adenosine triphosphate and is considered as the universal energy currency for metabolism. This allows organisms to reproduce, grow, and perform other life functions. Microorganisms, like macroorganisms, gain energy for life from their environment. Various ways of gaining energy are listed below:

- Photosynthesis is the conversion of light energy into chemical energy.
- Aerobic respiration is the process by which organic or inorganic substrates or electron donors are degraded/oxidized--completely to CO_2 in the case of organic matter, and oxygen is the terminal electron acceptor.
- Anaerobic Respiration is a process in which organic or inorganic substrates are oxidized/degraded, but using a substance other than oxygen as the terminal electron acceptor.
- Autotrophy is the process whereby production of organic biomass comes from inorganic carbon (CO_2).
- Heterotrophy is the process by which biomass is formed from pre-existing organic matter.
- Chemolithotrophy is the production of energy from the oxidation of inorganic electron donors. Examples: Sulfide Oxidation, Iron Oxidation, Nitrification (or ammonia oxidation).
- Fermentation is an anaerobic process in which organic compounds are degraded or oxidized incompletely resulting in an organic product.

Phototrophs are organisms that "eat" light by capturing the energy from the sun in order to transfer that energy to weak electrons in water to turn those electrons into high-energy electrons that can reduce other elements. This is necessary to carry out the two main functions of electrons or energy within living organisms and that is: (1) to have electrons flow downhill in order to convert electron energy in to a useful form of chemical energy for the cell, ATP, and (2) to create biomass by reducing carbon dioxide by way of the Calvin Cycle. Most phototrophs [and chemolithotrophs] are also autotrophs which mean that they can fix carbon.

They are labeled photoautotrophs. Chemotrophs are organisms that obtain their energy from chemical oxidation of organic (chemoorganotroph or heterotroph) or inorganic (chemolithotroph) substances. Heterotrophs obtain their energy by consuming other organisms. Combining these categories, we get the basic life strategies: photoautotrophs (e.g. plants), chemoorganotrophs or heterotrophs (e.g. animals, fungi), photoheterotrophs (some bacteria) and chemolithoautotrophs (bacteria and archaea only). Only in the bacteria - and among the bacteria within a single Winogradsky column - do we find all of these basic life strategies. (Deacon n.d.)

Microbial mats are the oldest ecosystems that exist on Earth. Although this ecosystem can be only a few millimeters thick, it carries out all the functions of a complex food web in that these microbes depend and are depended upon by other members of the community. It is an amazing arrangement how these microorganisms harvest energy. The top layer of the mat are filled with diatoms which are phytoplankton and are also photosynthetic- the brown algae and are encased in glass (i.e. silica shells). The blue-green bacteria known as cyanobacteria are located near the top of the mat. These microbes harvest energy from the sun and, thus, use the process of photosynthesis to carry out their life functions like the diatoms. Under this layer are the aerobic heterotrophs which use the oxygen produced by the cyanobacteria and diatoms to break down organic matter. Next come the chemolithotrophic bacteria, such as filamentous sulfur oxidizers, which use the redox energy contained in the gradient between the reduced sulfur compounds (produced at depth by the sulfate reduction or sulfate-reducing bacteria) and the oxygen (produced by the cyanobacteria).

The next layer comprises phototrophic bacteria that use infrared radiation which can penetrate deeper than visible light. These bacteria use the infrared radiation and reduced sulfur diffusing upward from below to carry out anoxygenic photosynthesis--meaning that oxygen is not produced. The fermenters are next in the mat. These microbes do not break down or oxidize their food (organic matter) completely, but transform it into different, partially oxidized organic compounds that other organisms in the community can utilize more readily as a source of electrons. Deep within the mat are the sulfate reducers, bacteria that use sulfate to burn [or oxidize] organic matter. These organisms breathe [or respire] sulfate rather than oxygen and produce hydrogen sulfide as a waste product, similar to the way we respire oxygen and exhale water vapor as a waste product. Sulfate-reducing bacteria account for the "rotten egg" smell typical of salt marshes and marine mud. The last of the organisms are the methanogens which produce methane--following depletion of sulfate, and are the least efficient in terms of producing energy to support cellular function. Thus, three of earth's major biogeochemical cycles are affected by activities of microorganisms within these mats: the oxygen cycle, the carbon cycle, and the sulfur cycle.

Out of the three cycles, the sulfur cycle is the most complex because of the multiple oxidation states of sulfur and the fact that some transformations occur at significantly different rates both chemically and biologically. (Madigan) As with the nitrogen cycle, most organisms cannot use elemental sulfur directly so they rely on sulfur-reducing and sulfur-oxidizing bacteria, in this case to convert sulfur into a useable form of sulfide (S^{2-}) or sulfate ($2H_2SO_4$). This can be turned to proteins. Sulfur is also important in the production of coenzyme A which is needed to produce energy in cellular respiration. The formula for this process is:

$$2S + H_2O + 3O_2 \rightarrow 2H_2SO_4$$

Photosynthetic bacteria, such as purple sulfur bacteria, can produce organic matter by using sulfur and light. The following formula illustrates that process:

$CO_2 + H_2S$ + light → $CH_2O + S$

Microbial mats provide an excellent source of nutrition for predacious organisms and therefore for these mats to survive, they must grow in extreme conditions such as hot, cold, or salty environments.

Chemical Processes within the Microbial Mat Community:

Cyanobacteria: $6\ CO_2 + 6H_2O \rightarrow 6CH_{12}O> +6O_2$

Aerobic Heterotrophs: $6CH_2O> + 6O_2 \rightarrow 6CO_2 + 6H_2O$

Chemolithotrophic Bacteria: $H_2S + 2O_2 \rightarrow H_2SO_4$ + ENERGY

Phototrophic Bacteria: $4CO_2 + 2H_2S + 4H_2O \rightarrow 4CH_2O> + 2H_2SO_4$

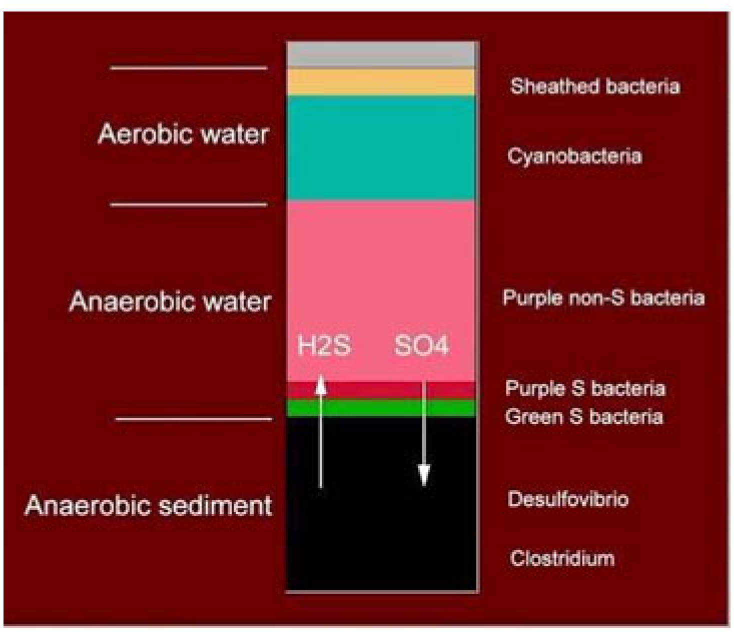
Fermenters: $6CH_2O> \rightarrow 2C2H_5OH + 2CO_2$

Sulfate Reducers: $SO_4^{2-} + CH_3COOH \rightarrow HS^- + 2HCO_3$

Methanogens: $CH_2COOH \rightarrow CH_4CO_2$

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Idealized Version of a Microbial Mat



Adapted/modified from: (Deacon n.d.)

Overview

Students will maintain an interactive notebook which is a notebook that contains all information that is given in the lesson. Hand outs are glued into the book and pages are based on the Cornell note taking strategy, which uses a two column page where questions are on the left and notes are on the right. An objective for the day is always at the top. This will always be on the right side of the notebook. Depending on the activity, the teacher will give questions and the students will answer those questions on the note side, or the teacher will give notes and the students will generate questions based on the notes. At the end of the page, students will summarize the notes and questions of that day. All pages are numbered and a Table of Contents will reflect the new page entries daily. Students will be introduced to new vocabulary terms and a foldable activity called a matchbook will be assigned.

A matchbook foldable is a 3×6 inch piece of colored construction paper that will be given for each new vocabulary term. Students will fold almost half-way down leaving a lip to be folded up resembling a matchbook. On the front, a picture is drawn depicting the vocabulary term. The inside top half will have the phonetic spelling. The bottom half will have the meaning of the term, in the students own words, and on the flap will appear the term itself. This can be given as a homework assignment. These matchbooks will be glued to the left side of the notebook opposite to the questions and notes of the day.

Students will also take part in a Socratic seminar. A Socratic seminar is a method of teaching developed by Socrates. He engaged his students in intellectual discussion by responding to questions with questions, instead of answers. This method encouraged the students to think for themselves rather than being told what to think.

Prior to the Socratic seminar, students are given a reading assignment from the in literature on history, health, philosophy, art or music to examine. After the students have read the text, open-ended questions are asked. The open-ended questions allow the students to think critically, analyze multiple meanings in text, and express ideas with clarity and confidence.

Participants in the Socratic seminar are expected to respond to one another in a respectful manner without bias or prejudice. They are also expected to listen carefully without interrupting. They must make direct eye contact with others and must use each other's names.

Activities

Lesson 1

Objectives:

Students will begin with a brainstorming session where they will write what they know about microorganisms, what questions they have about microorganisms, and what they have learned about microorganisms. This KWL chart will be kept in their interactive notebook, as well as displayed in the classroom. K stands for what students KNOW, the W stands for what students WANT to find out, and the L stands for what they have

LEARNED after being taught the subject matter. As new information is given through hands-on activities, such as growing microbial mats in the classroom, students will continuously add what they know and generate additional questions.

Materials: (for each student)

- •Green-colored spiral notebook
- •Scissors
- •Glue stick
- •Colored construction paper cut 6x2 inches
- •Colored pencils
- •KWL chart
- •Internet access

Materials: (for the class)

- •Chart paper
- •Colored markers

Lesson 2 (Adapted from The Microbial World: Winogradsky column: perpetual life in a tube)

Objective:

Students will build a Winogradsky column in the classroom in order to develop a keen sense of a, less-than-five millimeter, ecosystem that exists and gain an appreciation of the oldest ecosystem on Earth. This will be an ongoing investigation starting in early fall and continue throughout the school year since it takes from 2 to 3 months of incubation in order for different types of microorganisms to grow.

Materials:

1. Tall glasses or plastic tubes (30cm long, >5 cm wide) keep columns small to avoid too much hydrogen sulfide production/build up.
2. Pond mud

3. Shredded newspaper or hay (for cellulose)
4. Ground egg shells and yolk
5. Pond water

Procedure:

1. Fill tube or glass one third full of pond mud (omitting sticks, debris and air bubbles). Mud is supplemented with ~ 0.25% w/w calcium carbonate and ~ 0.50% w/w calcium sulfate or sodium sulfate--these will be converted to hydrogen sulfide by any sulfate reducers present
2. Mix together the shredded newspaper or hay along with the ground egg shell and yolk.
3. Add an additional layer of pond mud without the supplement (as noted in step one). This brings the column to two thirds full.
4. Add pond water to fill the tube and to saturate the mud.
5. Seal the column loosely and periodically add more pond water to adjust for evaporation.
6. Place in natural sunlight to incubate over several months.

Lesson 3

Objective:

Students will gain an understanding of the biogeochemical processes in microbial mats by identifying the producers, consumers, and decomposers of the microbial mats. By defining the terms, producers, consumers, and decomposers with respect to the chemical processes/reactions they are involved in, students will label a diagram of a microbial mat with these terms.

Materials:

•Diagram of a microbial mat community
•Three cards with pictures on one side and definitions on the other of producers, consumers, and decomposers
•Unlabeled diagram of microbial mats (See Appendix)

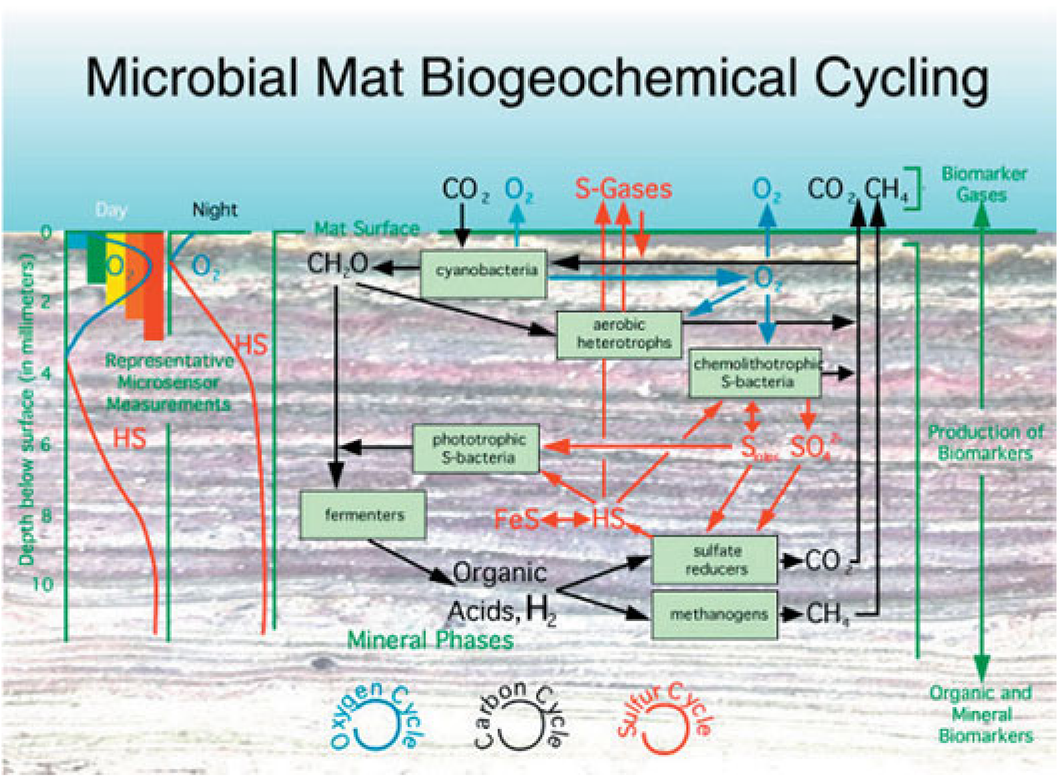
Procedure:

1. There will be three centers set up labeled producers, consumers, and decomposers.
2. Students will have distributed unlabeled diagram of microbial mats.
3. Students will rotate around to the stations drawing pictures of the microorganism or write a chemical reaction in the correct layer of the microbial mat diagram.

4. Students will get into a group of four to compare notes by having a Socratic seminar.

Lesson 4 (Adapted from Interactive Biogeochemical Cycle by Robin Bucaria, Dartmouth Middle School

Dr. Brad Bebout, NASA Ames Research Center)



Objective:

Students will investigate three cycles in microbial mats, the oxygen, carbon, and sulfur cycle by playing the cycle game.

Materials:

Cards labeled and laminated with the names and pictures of the microorganisms that exist within a microbial mat: Diatom; Cyanobacteria: Gloecapsa, Oscillatoria, Spirulina, Unicellular Cyanobacteria, Phormidium, Microcoleus; Aerobic Heterotrophs; Fermenters; Sulfate Reducers; Colorless Sulfur Bacteria; Purple Sulfur Bacteria; Methanogens

Procedure:

1. Place cards around the room and have four copies of each.
2. Divide class into seven groups.
3. Students will start at designated parts of the room and will take the card at the station.

4. Student will read card and follow the instructions and move to the next station that the card instructs them to go to.
5. After all students have moved through all seven stations, students will write about what they learned about the three cycles of the microbial mat.

Resources

Bibliography for Teachers

Bryant, Donald A., and Niels- Urilk Frigaard. "Prokaryotic photosynthesis and phototrophy illuminated." Science Direct, 2006.

The authors, researchers work from the Department of Biochemistry and Molecular Biology from Pennsylvania State University. They use data from genome sequencing projects which provide new information of five phyla that contain photosynthetic prokaryotes.

Deacon, Jim. The Microbial World: Winogradsky column: perpetual life in a tube. http://www.biology.ed.ac.uk/research/groups/jdeacon/microbes/wiongrad.htm (accessed May 24, 2010).

The author writes about the findings of metabolic diversity pioneered by two famous microbiologists, Sergius Winogradsky and Willem Beijerink. The author uses illustrations and diagrams to reveal this diversity grown in a laboratory called a "Winogradsky column." The author gives a description of each layer of the microbial mat which he names as a metabolic diversity of prokaryotes.

Falkowski, Paul G., Tom Fenchel, and Edward F. Delong. "The Microbial Engines That Drives Earth's Biogeochemical Cycles." Science Magazine, 2008: 1033-1039.

The authors submit a review examining the major redox reactions essential for life and biogeochemical cycles. Although there are huge genetic diversity that exists, there can be a trace back to a set core of genes and how these genes were passed microbe to microbe primarily by horizontal gene transfer.

Gonzales, Denise. MicrobesNASA. http://microbes.arc.nasa.gov/about/microbial.html (accessed 2010).

The author provides information about microbial mats and background of why NASA is interested in studying microbes due to the possibility of life, in microbial form, on other planets. The reason why NASA is interested in studying microbial mats is because the microorganisms have shown great resilience to extreme conditions, which can have far-reaching implications of life on other planets.

Michael T. Madigan, John M. Martinko, and Jack Parker. . Brock Biology of Microorganisms. Upper Sddle River: Pearson Education, Inc., 1984.

The authors have integrated the fundamental principles from past discoveries with the "state-of-the-art science of present-day technology which enables them to give detailed analyses of microbial cells. These new discoveries have catapulted microbiology into other disciplines such as ecology, agriculture, and medicine.

The authors have provided core fundamental principles which every student in microbiology should know. They then introduce microorganisms and how they evolved over time. Following, they outline the essential concepts of virology. Then viral diversity follows.

Jurkevitch, Edouard, Ed. Predatory Prokaryotes-Biology, Ecology and Evolution. . Heidelburg: Springer-Verlag Berlin, 2007.

Authors studied predatory bacteria through population dynamics and community structures. In their study they uncovered the flow of energy in ecosystems of bacteria and studied bacterial lifestyles and adaptations.

Newman, Dianne K. "How Bacteria Respire Minerals." Science, 2001: 1312-1313.

The author chronicled this article for the American Association for the Advancement of Science. The author is in the Division of Geological and Planetary Sciences from California Institute of Technology. In this article it is revealed how microbes use minerals for respiration. It states how these microbes do these still remains a mystery because using an electron microscope to observe this reaction leads to the destruction of the microorganism.

Speer, Brian. Introduction to the Cyanobacteria: Architects of earth's atmosphere. January 12, 2005. http://www.ucmp.berkley.edu/bacteria/cyanointro.html (accessed May 17, 2010).

The author gives helpful insight to what cyanobacteria are, where they exist, and how long they have existed. The author also tells the importance of cyanobacteria in the production of oil deposits, providing nitrogen fertilizers to rice and beans, and in shaping the course of evolution.

Staley, James T., Robert P. Gunsalus, Stephen Lory, and Jerome J. Perry. Microbial Life. Sutherland, Mass: Sinaur Associates, Inc., 2007.

The authors reveal information on sulfur-oxidizing species such as the guild of sulfur-oxidizers. They discuss microbial mats and look at biofilms as communities. Dominant manifestations of life on Earth exist by primary producers and nonphotsynthetic archaea. Energy comes from reduced sulfur compounds.

Reading List for Students

Biddle, Wayne. MICROBES - KIDS DISCOVER Magazine. Anchor Books, 2002.

The author introduces to children that microbes are everywhere, including on your skin, in your mouth, and inside your organs, but don't fear, most microbes are harmless and some are beneficial to us.

Dyer, Betsey Dexter. A Field Guide to Bacteria. Cornell University: Ithaca, NY, 2003. (pp. 32-33 for guide on using microbes to seek life on other planets, pp. 232-275--cyanobacteria)

The author offers this field guide to the amateurs looking to explore the microbial world and how microbes are not all pathenogenic. We find microbes in certain foods we eat such as yogurt, cheeses, wine, and ale, to name a few.

Farrell, Jeanette. Invisible Allies: Microbes That Shape Our Lives: Farrar Straus Giroux, April 2005

The author informs students about how microbes help us in preserving our foods by digesting foods and transforming it by decomposition in order for the cycle to repeat itself. The author provides illustrations and amusing anecdotes.

Padilla, Michael, Ioannis Miaoulis, and Martha Cyr. Science Explorer: From Bacteria to Plants. Pearson Prentice Hall. November 15, 2007

The authors provide a juvenile textbook written for children/young adults in grades seven to nine.

Sachs, Jessica Snyder. Good Germs, Bad Germs: Health and Survival in a Bacterial World: Hill and Wang: New York 2007

The author explains that although public sanitation and the use of antibiotics have increased the life span in humans, it also creates other problems by destroying the helpful microorganisms that we need for survival, thus creating new problems with our immune systems.

Appendix: "Implementing District Standards"

6.2 - An ecosystem is composed of all the populations that are living in a certain space and the physical factors with which they interact.

Populations in ecosystems are affected by biotic factors, such as other populations, and abiotic factors, such as soil and water supply.

Populations in ecosystems can be categorized as producers, consumers and decomposers of organic matter.

> C 4. Describe how abiotic factors, such as temperature, water and sunlight, affect the ability of plants to create their own food through photosynthesis.
> C 5. Explain how populations are affected by predator-prey relationships.
> C 6. Describe common food webs in different Connecticut ecosystems.

6.4 - Water moving across and through earth materials carries with it the products of human activities.

Most precipitation that falls on Connecticut eventually reaches Long Island Sound.

C 10. Explain the role of septic and sewage systems on the quality of surface and ground water.
C 11. Explain how human activity may impact water resources in Connecticut, such as ponds, rivers and the Long Island Sound ecosystem.

Worksheet for the Microbial Mat

Label the six layers of the Winogradsky column with the following organisms and color: Purple S bacteria, Cyanobacteria, Clostridium, Sheathed bacteria, Desulfovbrio, Green S bacteria, Purple non-S bacteria. Note: One layer contains two organisms