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GSSOP Mini-course Documentation
Spring 2003

Abstract

Cooperation and Competition in the Living World

Often we think of nature as a competitive environment where survival is a contest between and among species. However, cooperation is equally significant in the game of survival. In this mini-course, we will explore the competition and cooperation common to natural and agricultural systems. This course will highlight important and common symbiotic relationships across four kingdoms, including mycorrhizae, lichens, nitrogen fixation in legumes, and cellulose degradation in termites. To conclude, we will apply these relationships to agricultural systems. Key concepts are explored through discussion, and discovery activities. By becoming familiar with important ecological strategies, students will increase their knowledge and understanding of the many ways that organisms interact to ensure their survival.

Introduction

This course was taught in a 5-8 student classroom where students were not used to having slides or visuals except on the board, and the mode of classroom teaching was lecture with many questions. Quizes were given on material that was covered the day before or contained in the readings handed out each day. Microscopes and lab equipment were not available without a field trip, and students were not accustomed to working in groups or with each other. The course had to be taught only twice a week, so continuity was a problem. Therefore, this course is very presentation/discussion oriented rather than activity oriented. The subject also is somewhat abstract, but beautiful illustrative pictures are available on the internet.

Overall question: How do organisms cooperate in a competitive world?

Goals:

Students should understand

- That organism cooperate in many ways and be able to name some examples
- That cooperation is ubiquitous
- That historically the idea of cooperation has been resisted in science
- That cooperation is one way to compete for nutrients and other means of survival
- That humans play a part on every scale from inside our cells to our role as agriculturalists

I think students were able to get the main points of this course, though it is not clear if they understand that symbiosis is a method of competition. Generally, this course would be improved if it could be taught in one piece rather than spread over a month. It would be a good idea to teach the course after students have studied cell biology and been introduced to bacteria rather than to students who know/remember very little biology. It could also be improved if it could be made more active rather than passive learning with the use of microscopes or other means for students to engage more in subject matter. In a classroom more accustomed to students working together, most worksheets could be done in groups, and group discussions of material rather than more didactic discussion would probably engage students more.

Biography

Rachel grew up in Ithaca, NY, except for her year in Scotland when she was a junior in high school. She earned her BS at Cornell University in Natural Resources that included a semester abroad in Israel. To further pursue her interests in forest ecology and international development she attended the Yale School of Forestry and Environmental studies before joining the Peace Corps. She served in The Gambia, West Africa where she facilitated a community forestry project in her region and agroforestry practices in her village. She learned Mandinka and local culture and shared her own. When she returned to United State, Rachel worked as a technician in Cornell's Department of Horticulture, doing research on apple and other fruit orchards. Currently Rachel is a graduate student in the Education department at Cornell earning her certification to teach biology and earth science to secondary school students.

Individual Session Descriptions

Session 1. Introduction to cooperative relationships between large organisms.
Duration: 55 minutes

Materials: handout, and power Point presentation, laptop computer, slide projector, screen to project slides on.

Learning Outcomes: Goals for this session were to introduce concepts of cooperation in nature/evolution between organisms we can see, and to place humans in this context as well. I also wanted to show students pictures of things they may not have observed before.

Activities/procedures: This session's discussion/slide presentation discusses the relationship humans and plants have in evolution, some definitions of interactions between species, and some examples of mutualisms among multi-cellular organisms. The agenda/discussion questions were given on a handout for them. It contains questions, a quotation to discuss, and space for them to write in definitions:
Activities that would have happened had their been enough time:

- Each partner write the name of organism that are big enough to see
- Classify the relationship between the two as cooperating or competing or neither. If it is neither figure out how they might be related through other organisms.

Suggestions- this session went well. It would have been nice to have the definitions well formulated before hand, as these particular students were not adept or willing to construct their own wording.

Session 2: Introduction to Endosymbiotic Theory: Prokaryotes and Eukaryotes
Duration: 55 minutes

Learning Outcomes: Students should be able to explain the main differences between bacteria and Eukaryotes, and think about how they relate in an evolutionary context.

Materials: handout, and power Point presentation, laptop computer, slide projector, screen to project slide on.

Background information: Endosymbiotic theory is one explanation for how eukaryotic cells evolved, and is important for students to understand that inside all of our cells are organelles that were once bacteria. We can think of ourselves in cooperation with bacteria. Students need to be introduced to the two types of cells, prokaryotes and eukaryotes to see how one could be inside of the other.

Activities: introduction and discussion with slides

Procedure: Students should consult a partner and discuss what you know about bacteria? Consider size, shape, where they live, reproduction, and function
A PowerPoint presentation shows bacteria and introduces key aspect of prokaryotes and Eukaryotes. Students are asked to articulate how bacteria are different from the cells in our bodies based on the slides and to consider how we are related to bacteria in evolutionary trees.
Students are given handouts on bacteria to read for homework, and they will be given a quiz the next day.

Suggestions: Students might need a better background in evolution to understand the concept of common ancestry. Otherwise they will misunderstand the theory.

Session 3: SET –endosymbiotic theory
Duration: 35 minutes
Learning outcomes: students should be able to explain the basic theory that mitochondria and chloroplasts are derived from bacteria, and have some understanding of why this theory was not easily accepted.

Activities: short lecture and work sheets

Materials: handouts
Background Information: students should have read a handout given the night before some they have some idea on the theory and therefore would be ready to ask questions.

Procedures: short lecture explaining what the theory is, Lynn Margulis role in getting the theory accepted, and why this was difficult. Then students should do the first work sheet. We should go over it. And then they should start the second one and finish it for homework.

Suggestions: Because students were not given the handout the night before they were confused about the theory, and not ready to ask questions. They also were not prepared to do class work in class and expected lecture only. Make sure of context of class before giving out this assignment.

Session 4: Nitrogen Fixation
Duration: 30 minutes
Learning Outcomes: students gain experience with planting seeds, and become aware that bacteria can help plants. Students should be exposed to the concept of what nitrogen is and that it is important for living things but difficult to obtain even though it is all around them.

Activities: short discussion, planting seeds

Materials: nutrient deficient (we hope) potting soil. (We used potting soil mixed with vermiculite), rhizobia bacteria mixture, soaked snow pea seeds, one pot per student, plastic spoons for handling bacteria coated seed. Jar to use for coating seed with bacteria, container for non-coated seed. Water/watering can.

Background information: We hope students will be able to see rhizobia nodules on the plants once they grow. Nutrient deficient soil is necessary, so there is no guarantee that this experiment will work. Pairs of students will plant some seeds with bacteria and some without for a controlled experiment to see if the rhizobia form nodules and if it helps the plant grow better.

Procedure/Activities: Short discussion where students think about what living things need to survive, and how protein and DNA are important. These things contain Nitrogen. We discuss what nitrogen is and how people and plants obtain it. Then explain about nitrogen fixing bacteria and how they associate with plants. Next students go outside and do the planting.

Suggestions: It makes sense to have tested the soil and experiment before hand, but I did not have time or space to do this, so I do not know the outcome or how long it will take before we can see roots and nodulation.

Lesson 5: Fungi and their associations
Duration: 40 minutes

Learning outcomes: students will be able to explain that lichen is an association of fungi, algae, and sometimes bacteria. They will be able to name some things that humans use lichen for, and they will be exposed to the idea that fungi associate with trees to provide nutrients.

Materials: PowerPoint presentation, laptop computer, projector, screen, handout with background information on lichen

Activities: PowerPoint presentation and Discussion

Procedures: Use PowerPoint slides to create discussion. The discussion starts by taking a little time to find out what students know about fungi and giving them some main features of fungi. Next we discuss Beatrix Potter's role in the discovery of lichen as an association. Next there is an explanation of the lichen association. Finally, the human uses of lichen are discussed and described. At the end a hand out is given with all the information and some extra

Suggestions: if time allows, a lichen discovering field trip would be fun.

Lesson 6: Review and Corals
Duration: 35-40 minutes

Learning outcomes: students are reminded of what they have already learned. Students understand that Coral is an association with algae, and the stresses affecting it. Students understand that algae support the food chain.

Materials: handout for review, PowerPoint presentation with animations, lap top computer, projector, screen, and reading handout with information

Activities: discussion/presentation with movie

Procedure: review terms, discuss past examples, remind students the algae's role in lichen, Use PowerPoint presentation to introduce students to Coral and its importance, explain the symbiosis, and how it relates to the food chain. Explain Coral bleaching, its causes, and how it relates to the symbiosis.

Suggestions: Have more samples of Coral/ scenes from movies/ or field trip to see aquariums

Sessions 7-8: Hot vent associations/creative activity
Duration: 50+ minutes
Learning outcomes: students will be exposed to hot vent communities. Students will understand another example of how symbiotic bacteria support the food chain

Materials: Power point Presentation, laptop computer, projector, screen, handouts
Activities: Lecture/discussion. Creative assignment.
Procedure: Discuss the discovery of sea vent communities with Power Point Presentation and animation. Discuss Colleen Cavanau's contribution, and how the sulfur bacteria support the community. Give out hand out with creative assignment that asks students to come up with a symbiont they would like to have, what it would do for them, and what they would do for it.

Suggestions: It would be better for students to present their creations in some way, rather than just have them do a work sheet. The teacher said they would discuss them the next day.

<u>Resource Materials: worksheets and readings</u>

Worksheet/Agenda for GSSOP Session 1
Introductions
What do students know about evolution? How do species change over time? What is meant by "Survival of the Fittest?"

"What a trick this is for a plant, to produce a chemical so mysterious in its effects on human consciousness that the plant itself becomes a sacrament, deserving of humankind's worshipful care and dissemination. Such was the fate of *Amanita muscaria* among Indo-Europeans, peyote among the Amerian Indians, cannabis among the Hindus, Scythians, and Thracians, wine among the Greeks* and early Christians.

In the same way the human desire for beauty and sweetness introduced into the world a new survival strategy for the plants that could gratify it, the human hunger for transcendence created new opportunities for another group of plants. No entheogenic plant or fungus ever set out to make molecules for the express purpose of inspiring visions in humans-combating pests is the far more likely motive. But the moment humans discovered what these molecules could do for them, this wholly inadvertent magic the plants that made them suddenly had a brilliant new way to prosper. And from that moment on that is exactly what the plants with the strongest magic did."
Botany of Desire by Michael Pollen p.144-45

Other examples of human relationships with organisms

What organisms do flowers need to reproduce?
What other examples of cooperation between species do you know about?

Symbiosis

Mutualism

Commensualism

Parasitism

More general examples:
Ants and acacia
Ants and aphids
Ants and fungus
Cleaner fish
Birds on the buffalos
Trees and Squirrels

Reading on Bacteria handed out at the end of Session 2

Background on Bacteria

Bacteria are simple organisms that consist of one cell. They are among the smallest living things. Most bacteria measure from 0.3 to 2.0 microns in diameter and can be seen only through a microscope. (One micron equals 0.001 millimeter or 1/25,400 inch.) Scientists classify bacteria as **prokaryotes**.

Bacteria exist almost everywhere. There are thousands of kinds of bacteria, most of which are harmless to human beings. Large numbers of bacteria live in the human body but cause no harm. Some species cause diseases, but many others are helpful.

Certain kinds of bacteria live in the intestines of human beings and other animals. These bacteria help in digestion and in destroying harmful organisms. Intestinal bacteria also produce some vitamins needed by the body.

Bacteria in soil and water play a vital role in recycling carbon, nitrogen, sulfur, and other chemical elements used by living things. Many bacteria help decompose (break down) dead organisms and animal wastes into chemical elements. Other bacteria help change chemical elements into forms that can be used by plants and animals. For example, certain kinds of bacteria convert nitrogen in the air and soil into nitrogen compounds that can be used by plants.

A chemical process called fermentation, used in making alcoholic beverages and cheese and many other foods, is caused by various bacteria. Sewage treatment plants use bacteria to purify water. Bacteria are also used in making some drugs.

Bacterial cells resemble the cells of other living things in many ways, and so scientists study bacteria to learn about more complex organisms. For example, the study of bacteria has helped researchers understand how certain characteristics are inherited. Most types of bacteria reproduce quickly. This rapid reproduction enables scientists to grow large quantities for research.

Harmful bacteria

Some species of bacteria cause diseases in human beings. These diseases include cholera, gonorrhea, leprosy (Hansen's disease), pneumonia, syphilis, tuberculosis, typhoid fever, and whooping cough. The bacteria enter a human being's body through its natural openings, such as the nose or mouth, or through breaks in the skin. In addition, air, food, and water carry bacteria from one person to another. Harmful bacteria prevent the body from functioning properly by destroying healthy cells.

Certain bacteria produce toxins (poisons), which cause such diseases as diphtheria, scarlet fever, and tetanus. Some toxins are produced by living bacteria, but others are released only after a bacterium dies. A form of food poisoning called botulism is caused by toxins from bacteria in improperly canned foods.

Bacteria also cause diseases in other animals and in plants. Anthrax is a bacterial disease that infects many animals, especially cattle and sheep. Plant diseases caused by bacteria include fire blight, which occurs in apple and pear trees, and soft rot, which decays some fruits and vegetables. Bacteria also cause growths called crown galls, which attack various plants.

The structure of bacteria

Nearly all kinds of bacteria are enclosed by a tough protective layer called a cell wall. The cell wall gives the bacterium its shape and enables it to live in a wide range of environments. Some species are further enclosed by a capsule, a slimy layer outside the cell wall. The capsule makes the cell resistant to destructive chemicals. All bacteria have a cell membrane, an elastic, baglike structure just inside the cell wall. Small molecules of food enter the cell through pores in this membrane, but large molecules cannot pass through. Inside the membrane is the cytoplasm, a soft, jellylike substance. The cytoplasm contains chemicals called enzymes, which help break down food and build cell parts.

Like the cells of all living things, bacterial cells contain DNA (deoxyribonucleic acid). DNA controls a cell's growth, reproduction, and all other activities. The DNA of a bacterial cell forms an area of the cytoplasm called the nucleoid.

Scientists generally divide bacteria into groups according to shape. Round bacteria are called cocci, and rod-shaped ones are bacilli. Bacteria that look like bent rods are vibrios. There are two types of spiral-shaped bacteria, spirilla and spirochetes. Two or more bacteria linked together may be described by the prefixes diplo- (pair), staphylo- (cluster), or strepto- (chain). For example, streptococci are a type of round bacteria linked together in chains.

Bacteria live almost everywhere, even in places where other forms of life cannot survive. The air, water, and upper layers of soil contain many bacteria. Bacteria are always present in the digestive and respiratory systems and on the skin of human beings and other animals.

Certain bacteria, called aerobes, require oxygen to live, but others, known as anaerobes, can survive without it. Some anaerobes can exist either with or without oxygen. Other anaerobes cannot live with even a trace of oxygen in their environment.

Some bacteria protect themselves against a lack of food, oxygen, or water by forming a new, thicker cell membrane inside the old one. The cell material surrounding the new membrane dies. The remaining organism becomes inactive and is called a bacterial spore. Bacterial spores may live for decades or even longer because they can resist extremely high or low temperatures and other harsh conditions. If food, oxygen, and water again become available, the spores change back into active bacteria.

How bacteria move

Bacteria are carried long distances by air and water currents. Clothing, utensils, and other objects also carry bacteria. Various kinds of bacteria have flagella (thin hairs) that enable them to swim. Some species that lack flagella move by wriggling.

How bacteria obtain food

Most kinds of bacteria, called heterotrophic bacteria, feed on other organisms. Some species, known as autotrophic bacteria, manufacture their own food. For example, photosynthetic bacteria make food from carbon dioxide, sunlight, and water. Certain bacteria may be autotrophic or heterotrophic, depending on the food available. The majority of heterotrophic bacteria feed on dead organisms. Others are parasites. Some parasitic bacteria cause little or no harm to the host organism, but others cause diseases.

How bacteria reproduce

Most bacteria reproduce asexually --that is, each cell simply divides into two identical cells by a process called binary fission. Most bacteria also reproduce quickly, and some species double their number every 20 minutes. If one of these cells were given enough food, over a billion bacteria would be produced in 10 hours. Industrial and laboratory processes often produce such enormous numbers of bacteria. But in nature, bacteria lack an adequate food supply to maintain such a high rate of reproduction.

When bacteria reproduce by binary fission, the DNA in each of the two resulting cells is identical to the DNA in the original bacterium. Some bacteria can exchange DNA by a kind of simple sexual process called conjugation. Conjugation involves the direct transfer of DNA from one type of bacterial cell, called a male, to another type, called a female. DNA also may be transferred by viruses. Bacteria also may pick up fragments of DNA from dead bacterial cells. By transferring DNA, bacterial cells transfer individual traits. For example, bacterial cells that are resistant to certain antibiotics may transfer this characteristic to nonresistant bacterial cells.

History

The first living things on the earth probably included simple forms of bacteria. The oldest known fossils are those of bacteria that lived about 3 1/2 billion years ago. Some scientists believe certain bacteria gradually developed into multicelled organisms that were the ancestors of the more complex plants and animals of today.

Bacteria were first described in the mid-1670's by Anton van Leeuwenhoek, a Dutch amateur scientist. For many years, scientists believed that bacteria came from nonliving matter. But in the late 1800's, the French chemist Louis Pasteur showed that only living things can produce living things. Pasteur and Robert Koch, a German physician, helped develop the science of bacteriology (the study of bacteria).

By David Schlessinger Ph.D., Professor of Molecular Microbiology, Washington Univ. School of Medicine.

Classification of Bacteria

Eubacteria (eu = true) are the majority of bacteria and are subdivided by their method of energy acquisition into chemosynthetic, photosynthetic, and heterotrophic.

Chemosynthetic Bacteria

Chemosynthetic bacteria are **autotrophic**, and obtain energy from the oxidation of inorganic compounds such as ammonia, nitrite (to nitrate), or sulfur (to sulfate).

Photosynthetic Bacteria

Photosynthetic bacteria carry out conversion of sunlight energy into carbohydrate energy.

Heterotrophic Bacteria

Members of this large and diverse group must derive their energy from another organism by feeding. Two main types: saprophytic and symbiotic. Saprophytes feed on dead or decaying material and are important nutrient recyclers. Symbiotic bacteria live within a host multicellular organism and contribute to the health of the host. Examples include cows and other grazing animals: the bacteria convert cellulose from plant leaves and stems eaten by the animal into glucose for digestion by the animal. Normally cellulose is nondigestible.

The Archea

Archaebacteria are considered the oldest and most primitive organisms known. They have significant differences in their cell walls and biochemistry when compared to bacteria. The archeans are life's extremists, occupying environments that "normal" organisms find too harsh.

Three types of archaebacteria: methanogens, halophiles, and thermacidophiles. They live in extreme habitats.
from
http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookDiversity_2.html#Table%20of%20Contents

Reading to be handed out before Day 3
Background on Serial Endosymbiotic theory

One of the most fascinating concepts to gain popularity in recent times is the endosymbiotic theory for the origin of the eukaryotic cell, sometimes called SET (serial endosymbiosis theory) for short and sometimes called the xenogenous hypothesis. According to this theory: A prokaryotic cell capable of engulfing other prokaryotes, engulfed aerobic bacteria. Rather than digesting them, the bacteria remain, as symbionts, benefiting the host cell by removing harmful Oxygen and helping in the production of ATP (energy). As interdependence between the aerobic bacterium and the host cell grows, the bacterium becomes the mitochondrion. Some of these cells also engulf and keep blue-green algal cells which become chloroplasts.

These observations appeared to be supported later by electron microscopy when it was discovered that both organelles were surrounded by two membranes - the inner one supposedly belonging to the symbiont and the outer one a remnant of the membrane used by the host cell to engulf the symbiont. Today, the endosymbiotic theory is most closely associated with the work of Lynn Margulis .

Support for the endosymbiotic theory

The endosymbiotic origin of mitochondria and chloroplasts is widely believed because of the many similarities between prokaryotes and these organelles:

1.Mitochondria and chloroplasts are similar in size and shape to prokaryotes
2. Mitochondria and chloroplasts have their own DNA and their own ribosomes
3. Organelle ribosomes are more similar in size to prokaryotic ribosomes
4. Mitochondria and chloroplasts divide by fission, not mitosis.
5. Mitochondria arise from preexisting mitochondria; chloroplasts arise from preexisting chloroplasts (they are not manufactured through the direction of nuclear genes).
6. Many antibiotics that kill or inhibit bacteria also inhibit protein synthesis of these organelles
7. Phylogenetic studies using comparative ribosomal RNA sequencing shows that both organelles are related to Bacteria.

Handout/Worksheet for Session 3
GSSOP Lesson 3
The Theory of Endosymbiosis
Timeline:
1868 DeBary defines symbiosis
1860s-1907- Russians, Famintsyn and Merezhkovsky, study Lichen and make theories
1905-1920s Famintsyn and Merezhkovsky expound on and criticize theory of symbiogenesis. American scientists are puzzled as to how complexity arose. E.B. Wilson hints that plastids and mitochondria have many similarities with free-living bacteria.
1930's Kozo-Polyansky1920 incorporate natural selection into theory
1940s'-1950's- NO WORK
1960s- present- biochemical work by Russians and Americans. Lynn Margulis popularized enodosymbiotic theory starting in 1967 after a long battle against orthodoxy. Chloroplasts and Mitochondrian are cultured outside of eukaryotic cells.

From your homework reading answer the following questions:

What two organelles in a eukaryotic cell have their own genetic material (DNA)?

What functions do these organelles have in the eukaryotic cell?

How is the cell division of Eukaryotic cells different than that of bacteria?

What two organelles are thought to have been something like modern bacteria before they became part of eukaryotic cells? Why?

From your own knowledge about cell division and DNA answer the following questions:

Do you think these organelles reproduce at exactly the same time as the rest of the cell does?

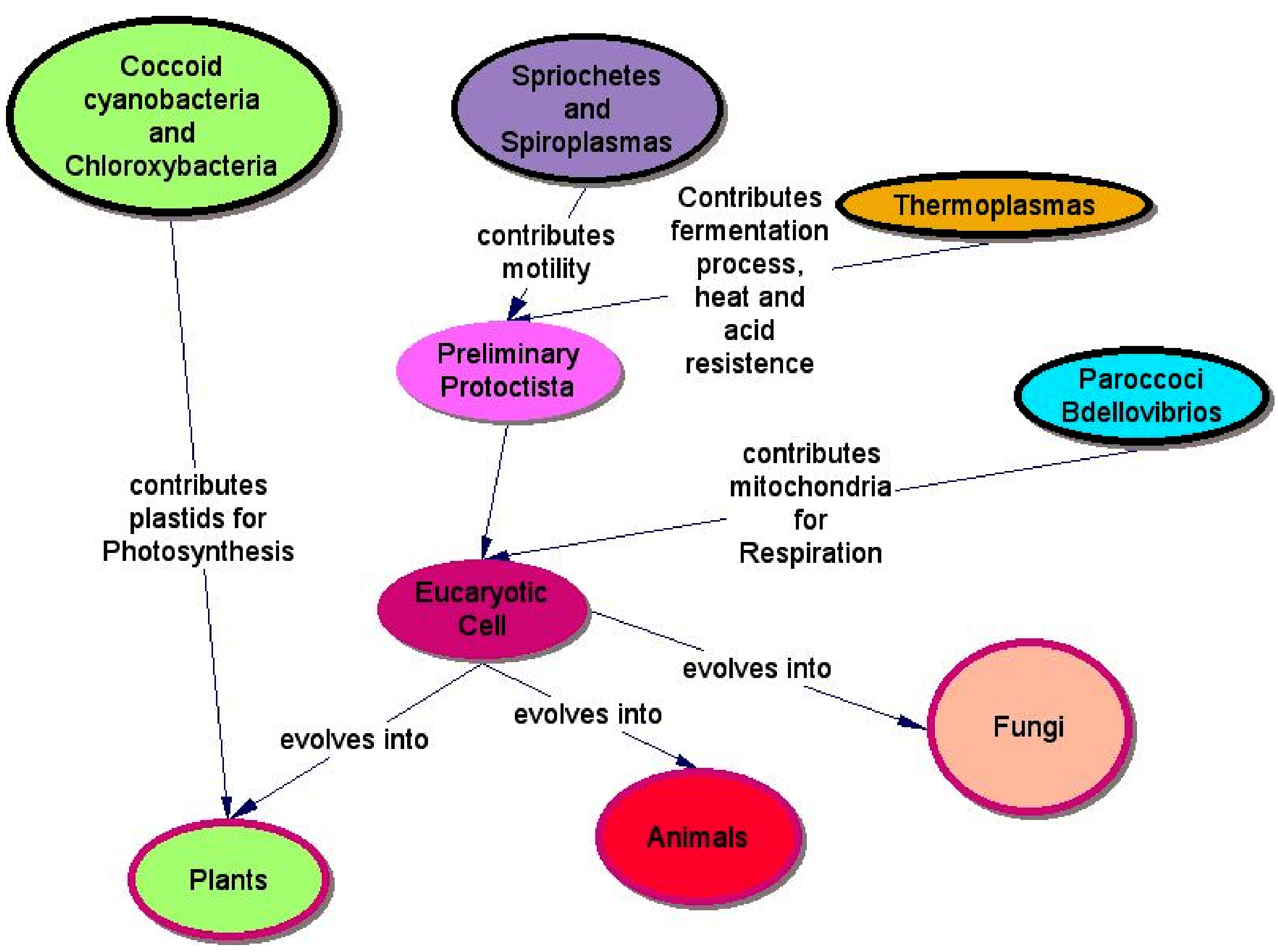
If not, why not?

If these organelles divide at a different rate than the cell, could this be a problem for the cell? Why?

If endosymbiotic theory is correct, which things are cooperating?

Which are competing?

Full SET Theory by Lynn Margulis:



Reading handed out after lesson 5
Background on Lichen

The plant-like appearance of lichens hides their true identity. Lichen is not a sing le organism, but the result of a partnership (mutualistic symbiosis) between a fungus and an alga and/or cyanobacteria. Some lichens are formed of three or more partners. The body of a lichen consists of fungal filaments (hyphae) surrounding cells of green algae and/or cyanobacteria.

In this amazing association the fungus benefits from the algae because fungi, having no chlorophyll, can't photosynthesize their own food. Lichen's fungal part is thus "fed" by its photosynthesizing algal part. The algal and/or cyanobacterial partner(s) possess the green pigment chlorophyll, enabling them to use sunlight's energy to make their own food from water and carbon dioxide through photosynthesis. They also provide vitamins to the fungus. Cyanobacteria can make amino acids directly from the nitrogen gas in the atmosphere, something neither fungi nor algae can do. The fungus, in turn, protects its partners from drying out and shades them from strong sunlight by enclosing the photosynthesizing partners within the body of the lichen. The algae benefit from the association because the fungus is better able to find, soak up, and retain water and nutrients than the algae. Also, the fungus gives the resulting lichen shape, and provides the cup-like reproductive structures. The lichen fungus provides its partner(s) a benefit (protection) and gains nutrients in return.

Lichens spread mostly by small pieces of their body being blown around. All the partners in the original lichen body are present in the fragment, so growth can begin immediately. Some lichens create soredia, balls of tissue made just for dispersal.

The lichen mutualism has allowed lichens to successfully colonize many different habitats. Lichens have a truly remarkable resistance to drought. Dry lichen can quickly absorb from 3 to 35 times its weight in water! Lichens can also absorb moisture from dew or fog, even from the air itself if the humidity is very high and the temperature is low. They also dry out slowly, making it possible for the photosynthesizing partner(s) to make food for as long as possible. This ability to quickly absorb and retain water from many sources makes it possible for lichens to live in harsh environments like deserts and Polar Regions, and on exposed surfaces like bare rocks, roofs and tree branches.

Lichens grow very slowly, sometimes only fractions of an inch in a whole year, and many do not recover well from disturbance or collecting. Most lichens grow slowly, probably because they live in environments where water is available for only short periods. They tend to live for many years, and lichens hundred of years old can be used to date the rock surfaces on which they grow. There are ~20 000 lichen species in the world, found from some of the hottest deserts to some of the coldest alpine habitats, beyond the reach of any tree. Some slow growing crustose species in these harsh environments can live to more than 1000 years old.

Ecologically, lichens are important because they often occupy niches that, at least sometime during the season, are so dry, or hot, or sterile, that nothing else will grow there. For example, often the only plant growing on a bare rock will be a crustose lichen.

Lichens are also important in making soil. Soil is made up of organic matter, such as decayed plants, and minerals. Species that grow on rocks infiltrate and wedge apart pieces of the rock by both pressure and chemical action. Some of their acidic secondary products dissolve the rock’s surface, freeing mineral grains. This is an extremely slow process, but the resilience and endurance of the lichen fungi puts time on their side.

Lichens are important in many ways in the habitat. Some make the nitrogen in the air usable to plants. They are homes for spiders, mites, lice, and other insects. All are important in the nutrient cycle in the places where they grow.

Humans have learned to use lichens in many useful ways. Lichens also make about 400 known "secondary products". It is thought that these chemicals are produced by lichens as defenses against disease and parasites, and, in some cases, to make the lichen taste unpleasant to animals. Some of these compounds are now used as anti-viral and anti-bacterial medications. Other secondary products are used to make everyday life more colorful and pleasant. Some are used to scent soaps and make perfumes. Others were used in the past to dye woolen cloth. Most colors were some shade of brown or yellow, but blue was produced from a few species. The discovery of synthetic dyes ended the demand for lichen dyes. The synthetic dyes provided many more colors, and did not fade. Lichen dyes are still used by some craft weavers who like their soft, quiet colors. Today, the only commercially important lichen dye is used to make litmus paper, to test the acidity of liquids. The litmus dye turns blue in "basic" (low-acid) solutions like ammonia, and red in acid solutions like vinegar.

Lichens can be an important food source in extreme environments. The Lapp people, who live above the Arctic Circle in Scandinavia and Russia, harvest lichens as winter food for their reindeer, just like farmers in temperate zones stockpile hay. Sheep in the deserts of Libya survive, in part, by eating crustose lichens growing on rocks.

Lichens can also tell us if the air is clear and clean because many lichens die when the air gets polluted. They differ in their sensitivity to air pollution, and the presence or absence of different lichens in an area has been used to map concentrations of pollutants. If you live where there are many lichens it probably means the air is clean. But, if there are only a few lichens in your neighborhood, the air you are breathing is probably clogged with automobile fumes or industrial wastes.

GSSOP 6 Handout

A little review

What is symbiosis?

Define Mutualism?

Define Parasitism?

What are some examples that we have talked about? (Name at least two)

For one example, List at least two partners AND describe what each partner gains from the other one

When is having a partner helpful?

Do you know of any other symbiotic relationships that we have not talked about yet?

Handout after Lesson 6

Coral Reefs
Rain Forests of the Ocean (excerpt)

Thomas J. Goreau

Corals: Architects of the Reef

Corals are simple, bottom-dwelling animals whose fundamental unit is the polyp, which has a common opening to take up food and excrete wastes, surrounding a ring of tentacles. Each polyp sits in its own cup in a limestone skeleton, which the coral constantly builds as it grows upwards. Polyps use weak stinging cells in their tentacles to capture small animal plankton from the water. Reef-building corals live in large colonies made by repeated divisions of genetically identical polyps. These colonies come in an astonishing variety of branching, leafy, or massive forms, which may grow continuously for thousands of years. They are related to jellyfish, sea anemones, and a variety of soft corals that lack massive limestone skeletons.

The cells of reef-building corals contain symbiotic algae that release most of the organic matter they make from photosynthesis to their coral hosts. Corals consequently look much like plants and grow over each other in competition for light. They are also able to take up dissolved and particulate organic matter from seawater. This wide range of potential food sources places corals at many levels of the food chain simultaneously acting like a producer, herbivore, carnivore, and decomposer. The algae remove carbon dioxide and excreted nutrients, while supplying food and oxygen, and greatly enhancing the rate at which the corals deposit their skeleton. Virtually all coral skeletons are white, but they are hidden beneath tissues with a wide range of colors, derived from pigments in the symbiotic algae.

As a result of their dependence on symbiotic algae, coral reefs can grow only in conditions suitable for the algae. Coral symbiosis requires warm, bright, clean marine waters, confining reefs to shallow well-lit tropical waters, free from excessive turbidity (muddiness) and pollution. Extremes of temperature, salinity, or light can cause corals to expel their algae, losing most of their food supply and capacity for rapid growth. This phenomenon is called bleaching because the corals lose color. Thus corals and coral reefs are extremely sensitive to environmental change and habitat degradation.

Human Stresses to Reefs

Easy access by the rapidly expanding human populations of adjacent tropical coastal lowlands is causing mounting stress to reefs. Corals can be directly damaged by boats, anchors, handling by divers, dredging, reef mining for limestone, oil spills, and leakage of toxic chemicals from land sources or passing ships. Spear guns, trawls, explosives, and poisons are often used to collect fish or reef organisms for food, aquarium specimens, jewelry, or curios. In most regions favored reef fish are severely depleted, and fish are smaller and less diverse.

Changes in fish populations may remove the species that control the abundance of other reef organisms (such as seaweeds) thus allowing the spread of "weedy" species. Deforestation of watersheds and coastal habitats greatly accelerates erosion, allowing soil washed into the sea to smother reefs. The reef structure ceases growth and is gradually eroded by organisms boring into and weakening it.

Drainage of canals in coastal wetlands damages reefs by freshwater and sediment discharges. If sewage generated by coastal populations does not undergo tertiary treatment to remove excess nitrogen and phosphorus, these nutrients stimulate prolific growth of seaweed, which overgrows corals. Expanding areas of dead or dying reef are seen around many coastal towns, resort areas, and populated areas in the tropics. Their tourism is largely based on diving, fishing, and boating in the reef waters, or on the sand produced by the death *of* reef organisms. If reefs die, sand replenishment is cut off and beaches are destroyed by erosion.

Starting in the 1980s, massive bleaching of coral reefs was reported in the Pacific, Caribbean, and Indian Oceans. In extreme events almost all corals in a reef may bleach white, and many die. The survivors slowly recover, taking up to 10 months to regain normal color and growth. During this period they are starving, unable to grow or reproduce.

These events appear to be due to unusually high water temperatures. They follow periods when water temperatures were one degree Celsius above This suggests that coral reefs may be among the most climate-sensitive ecosystems.

Reef recovery requires abatement of external stresses, limiting change to rates within the capacity of the reef to adapt. This includes treating sewage, reforesting watersheds, controlling over fishing, stopping destructive utilization of reef organisms and materials, and preventing global warming.

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Handout after Lesson 7
Microbiologist-Aquanaut Colleen Cavanaugh Receives Tenure

By William J. Cromie

Gazette Staff

Not many people have visited with 6-foot-long, bright red worms on the boiling bottom of the ocean. It sounds like a Jules Verne fantasy, but newly tenured Professor of Biology Colleen Cavanaugh has seen these and other strange creatures on voyages to the bottom of the deep sea.

As a first-year graduate student, she discovered what makes life possible in a hell-on-earth where the sun never shines, temperatures can exceed 250 degrees F, and the ocean exerts pressures of thousands of pounds on every square inch of an animal's body. Giant worms, huge clams and mussels, and strange shrimp thrive in such conditions because of one-celled bacteria who live on and inside them. The bacteria turn sulfur, methane, and other inedibles into organic molecules that their hosts feed on.

"These bacteria are the primary producers of biological matter; they form the base of the food chain, at hydrothermal vents on the bottom of the Atlantic and Pacific," Cavanaugh says.

She went on to find the same kind of partnership among clams living in shallow eelgrass beds and mudflats along the coast of New England.

The Inside Life

An important evolutionary angle of Cavanaugh's research involves the belief that important parts of our cells and those of other animals and plants were once symbiotic bacteria. She is tracing the history of how free-living bacteria take up life inside other creatures, and then become integral parts of their hosts.

Examples include chloroplasts, now present in every plant cell and vital for turning sunlight into food. All plant and animal cells also boast mitochondria, former bacteria that provide energy for cell metabolism, much the same way that sulfur-eating bacteria provide fuel and food for giant tube worms.

Growing up in Detroit, Cavanaugh never imagined she would pursue such lineages and lead the life of a scientific Captain Nemo. She did, however, announce in the second grade that she wanted to be a scientist.

"In English class you had to write, in science class you didn't," she recalled.

"So science became my first choice."

By the seventh grade, Cavanaugh leaned toward biology and ecology. "I thought about working on the Great Lakes, and decided to major in biology at the University of Michigan," she said.

In her sophomore year, Cavanaugh heard about a course in marine ecology at Woods Hole, Mass. The course turned out to be one of those events that change a person's direction in life.

Her research involved wading into cold water to study the mating habits of horseshoe crabs. But she "fell in love" with Woods Hole and the relaxed camaraderie and cross-fertilization among biologists, geologists, and other scientists of the sea. Leaving all that at the end of the course turned out not to be a problem because her car had broken down and she could not get back home.

Cavanaugh began searching for a waitress job, but luck intervened and she replaced a last minute dropout in a Boston University undergraduate research program. She went back to working with horseshoe crabs. She also met then later married Phillip Gschwend, an M.I.T. graduate student who was studying the development of lobster claws.

In 1977, Cavanaugh earned her undergraduate degree and moved to Woods Hole to work at the Marine Biological Laboratory there. During the next two years, she abandoned horseshoe crabs in favor of bacteria, creatures that impressed her for their ability to live anywhere. She thought that a life of research and teaching would be ideal.

Gutless Creatures

During her first year as a graduate student, Meredith Jones, curator of worms at the Smithsonian Institution, gave her a giant tubeworm captured by a research submarine working on the bottom of the Pacific. These worms lack both a mouth and a gut, and she wanted to figure out how such an animal lives.

The biggest clue involved sulfur crystals packed in its long, thin body. Cavanaugh believed, correctly, that bacteria inside the worms use sulfur to fix carbon into edible molecules. The bacteria nourish their hosts, who in turn provide them with the chemicals, and oxygen they need to survive, as well as a stable place to live. Hot water pouring out of the tears in the ocean floor and undersea currents would, otherwise, float them away.

Such vents spew mineral-laden waters through many rifts in the bottom of the world ocean. Cavanaugh discovered that all the major animals living on or near these subsea springs live in partnership with bacteria who convert the minerals to food. In the middle of the Atlantic, for example, lives a shrimp whose body is covered with bacteria. The little symbionts provide nourishment for both the shrimp and other bottom dwellers.

Cavanaugh found the same kinds of partnerships among bacteria and clams living in shallow water. She also discovered a new species of deep-dwelling mussel in the Gulf of Mexico that shares its body with methane-utilizing bacteria. Methane, or marsh gas, is of no use to the mussels until bacteria convert it to carbon. The shellfish then munch the bacteria.

Cavanaugh worked on marine life in the laboratory and onboard ships for 12 years before she won a place on the deep-diving submarine *Alvin* . She went to the bottom of the Gulf of Mexico off Florida for the first time in 1992.

Last April, she dove to a depth of 8,200 feet off the west coast of Mexico and came face-to-no-face with the giant tubeworms at last. Through a small porthole, she watched their brilliant red plumes sweeping the oxygen and sulfur from the black sea for the benefit of their body guests.

Some people think life on Earth began in these deep, hot springs. Cavanaugh thinks that "the idea makes sense because some of the oldest forms of free-living bacteria show signs of being heat-loving organisms."

She now focuses on understanding the nature and evolution of the partnerships that allow these host-guest combinations to live in otherwise inhospitable places. The host cannot survive without the food produced by its guest; and the guest cannot survive without a stable place to live.

"From what I've been able to determine so far, symbiosis arose many times over hundreds of millions of years of evolution. Today, there are tens of thousands of different bacterial species living in soil, water, and even thousands of feet below the ocean bottom, but we've only identified about 4,000 of them.

A sign at the entrance to Cavanaugh's office applies equally well to her professional and personal life. It reads: "It's the little things in life that matter."

For Last Session

Creative assignment

If you were designing a better human, and had unlimited resources and magical powers to create life, what type of mutualist partner might you want it to have?

1. What will you call the partner?

2. How will the partner help the human?

3. How will the human help the partner?

4. How is the partner acquired and passed on to the next generation?

5. How big is the partner?

6. Will the human look different? If so how?

7. What does it look like? Draw a sketch of the partner

Appendices

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