PROFESSIONAL DEVELOPMENT

AP® Environmental Science

Ecology

Special Focus

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Introduction

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One of the essential underpinnings of a course in environmental science is a basic understanding of ecology. The irony lies in the nature of the two courses. Environmental science is an introductory college course and is often a college student's first foray into the natural sciences arena. However, ecology is typically an upper-level course at most colleges and universities, requiring numerous introductory courses prior to enrollment. Ecology is the relationship between organisms—at the individual, species, population, community, and ecosystem level—and their environment. In order to understand environmental science, which is basically the human impact on these organisms and their interactions, one must grasp concepts that are actually quite difficult for the budding scientist. Therefore, a special focus devoted to ecology seemed prudent, particularly since both multiple-choice and free-response questions on the AP® Environmental Science Exam will directly and peripherally address concepts of ecology.

In this Special Focus publication, teachers will be provided with discussion and pertinent examples of numerous ecological precepts. The first section contains an introduction to energy, including photosynthesis, cellular respiration, and matter cycling and energy flow through ecosystems. This section is paramount to an understanding of AP Environmental Science and actually addresses one of the major themes of the course: Energy conversions underlie all ecological processes. Pertinent information is provided regarding trophic levels, food webs, and ecological pyramids. Another section discusses primary productivity because it potentiates the complex nature of the niche structure and therefore impacts the biodiversity of ecosystems. Special instruction is given to the terminologies used for species within various niche structures. An entire section is devoted to discussing the evolution, natural selection, adaptation, and interactions of species. The evolution section addresses another of the themes—that Earth is one interconnected system—upon which the AP Environmental Science course is based. Finally, there is a discussion of community interactions, including succession, disturbance, resilience, stability, edge effect, and island biodiversity. Numerous exercises have been produced for this Special Focus publication, including adaptation and natural selection labs, succession, primary productivity, and ecological footprint and Shannon-Weiner biodiversity index calculations.

Since students have traditionally had difficulty with the variety of calculations required on the AP Environmental Science Exam, many different types of calculations and exercises have been included in this guide. It is hoped that students will master and acheive confidence in their mathematical skills after they have sufficient practice to increase their proficiency. Calculations are required not only in the multiple-choice portion of a typical AP Environmental Science Exam; sometimes the free-response section incorporates several different calculations so that the questions can be answered fully.

Ecosystem Energy Flow: An Introduction to Energy and Laws of Thermodynamics

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Although students entering an AP Environmental Science class have taken previous science classes, generally they do not have an understanding of the role that energy has in their biological environment.

In high school physics class, students are usually taught to define energy as the ability to do work, which might be expressed as a force moving through a distance. They are further taught that energy may be either kinetic (an energy associated with motion) or potential (an energy associated with position). They may encounter energy in mechanical, heat, light, and electrical form, among others. When studying kinematics, they learn that not all of the energy put into a system results in useful energy; some is converted to heat due, for example, to friction. This phenomenon leads to an understanding that energy cannot be created or destroyed but can be transformed from one form to another.

Often neither chemistry nor physics courses include a discussion about the energy necessary to hold together the parts composing atoms or the energy required by atoms to form molecules. Energy levels may be discussed in both courses, but often a conceptual understanding of energy is not achieved. It is with this background that students enter the AP Environmental Science class.

Thermodynamics, the principles that govern energy relationships, is very important to an understanding of our biological environment. Such energy relationships describe constraints on the generation of heat, the transformations of energy, and energy transfer within a system or to the surroundings. In other words, if energy is added to a system from its surroundings, it may return to the surroundings in a different form. The first law of thermodynamics states that energy is conserved when both a system and its surroundings are considered; that is, energy can neither be created nor destroyed but may be transformed from one form to another, including the exchange of energy with its surroundings. The second law is sometimes referred to as the law of entropy. To put it simply, in any energy transformation, some energy is lost as unusable energy in the sense that work cannot be performed.

Any discussion of energy in an environmental science class must investigate the two following questions: (1) Where does the energy needed for living organisms originate and (2) how is energy used by these organisms? At the onset of a discussion about energy relationships, it is important for students to think of the surface of earth as a system subject to the first two laws of thermodynamics. Most of the energy added to this system arrives on earth in the form of electromagnetic radiation from the sun. It has been estimated that 58 percent of the radiation directed toward earth is reflected or absorbed as heat by our atmosphere, that less than two percent of this remaining radiation is used by plants, and that the balance is transformed on earth's surface into heat. Other sources of energy that should be noted include energy released by geothermal and volcanic activity, as well as naturally occurring nuclear reactions.

Living organisms must conform to the laws of thermodynamics. Consider living organisms as temporary storage units for useful energy, whereby one organism can be used by another as a source of energy. In its transfer from one organism to another, useful energy is lost to the environment in the form of heat until the useful energy is ultimately consumed. As energy cannot recycle, there is a continuous requirement for new energy to enter the system. Photosynthesizing organisms use a series of oxidation-reduction reactions based on solar input to produce and store their own carbohydrates, which then become the energy source for other organisms.

Ecosystems and Energy

The food consumed by an organism will undergo a number of chemical reactions that are collectively referred to as metabolism. Materials in addition to water are transported across cell membranes. These processes are facilitated by carrier proteins embedded within the membrane. The detailed transformation of nutrients is beyond the scope of this discussion. Descriptions of these processes may be found by searching for information on the Krebs (citric acid) Cycle. Students should understand that organisms take in nutrients, the energy of which becomes available through oxidation and reduction reactions.

Extremophiles should be briefly considered in this course. These organisms live under severe conditions; some never receive sunlight or may be found clustered around underwater vents producing superheated boiling water. Their source of energy is through chemosynthesis, the process in which inorganic compounds such as nitrites, hydrogen sulfide, and hydrogen gas provide the necessary energy for these organisms to produce their own organic food. This information is sufficient to explain chemosynthesis without going into further detail.

Photosynthesis

Green plants are able to make food by producing ATP (a carrier for energy) and NADPH (a carrier for electrons used in the synthesis of glucose) in their chloroplasts, which then reduce carbon dioxide and water to form a carbohydrate (glucose) *only* in the presence of sunlight and chlorophyll. This process is actually a complex series of reactions where radiant energy is transformed into chemical energy. This series of reactions produces most of the oxygen in our atmosphere.

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

carbon dioxide | water light & chlorophyll | glucose | oxygen

Cellular Respiration

In this process, carbon dioxide, water, and available energy are produced by the oxidation of glucose. This series of chemical reactions occurs in all living cells. In aerobic organisms (those that can utilize oxygen). It is a process that requires oxygen and occurs at the cellular mitochondria; however, the first steps in the transformation of glucose take place in the cytoplasm rather than within the mitochondria and do not require oxygen. If the reaction never proceeds to the mitochondria, the organism has carried out anaerobic respiration, also known as fermentation. These first processes are known as glycolysis (glucose breaking). Although heat is released in this process, some of the energy is used to replenish the supply of ATP (a carrier for energy) and NADPH (a carrier for electrons used in the synthesis of glucose).

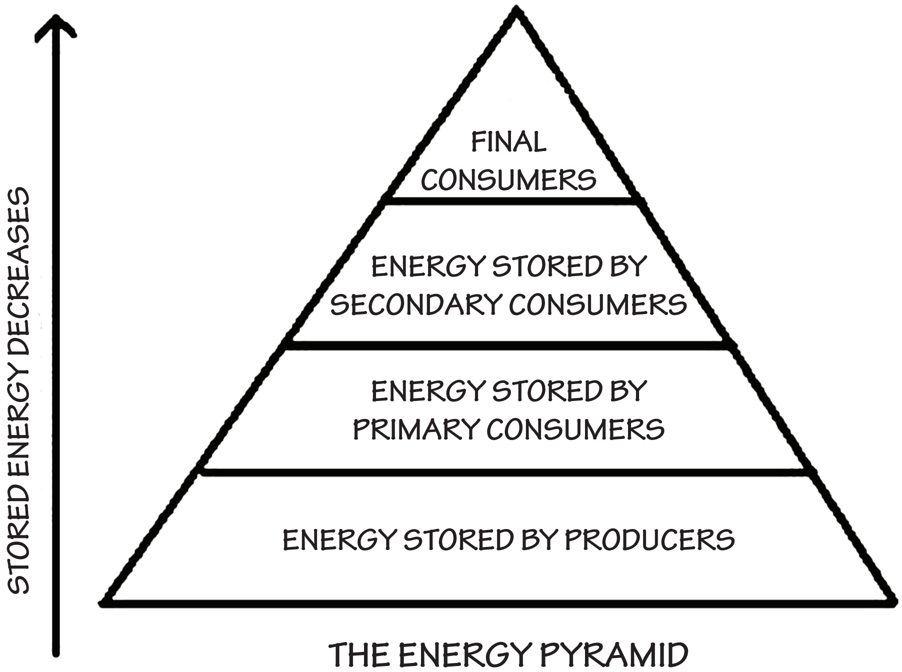
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

glucose | oxygen | carbon dioxide | water

Trophic Levels

A producer, or autotroph, is an organism that makes its own food by either photosynthesis or chemosynthesis. A consumer, or heterotroph, is an organism that receives its energy from other organisms. Each step in the transfer of energy (autotroph to heterotroph and heterotroph to heterotroph) is known as a trophic level. The laws of thermodynamics apply to the energy flow through an ecosystem; therefore, less energy is available to organisms at each higher trophic level. This decreased amount of available energy at each trophic level is due to the amount of energy required by an organism to carry out the daily functions of living. It is estimated that only 10 percent of the energy at each trophic level is available to organisms at the next higher level.

Decomposers are often overlooked when considering trophic levels. These organisms receive their nutrients and energy while breaking down and recycling organic materials. Because their activity permits nutrients contained within deceased



THE ENERGY PYRAMID

organisms and waste products to be available to other trophic-level organisms, decomposers are important to the flow of energy and matter through the ecosystem

Food Chains and Webs

Energy flow through an ecosystem may be traced through its food chain; that is, by tracking down what feasts upon what, we can follow the flow of energy. At the lowest level of the food chain, we find the autotrophs—organisms that manufacture their food by either photosynthesis or chemosynthesis. Generally, herbivores eat autotrophs and are considered "primary consumers." Carnivores dine on the primary consumers and are designated as "secondary consumers." This, of course, is stated as the simplest food chain. In nature, as we are well aware, nothing is quite that simple. In an ecosystem, there are numerous food chains linked to each other to form a complex "food web."

Ecological Pyramids

The trophic structure of an ecosystem may be represented by an ecological pyramid. The base of the pyramid is composed of the producers, and each trophic level above the base represents consumers higher on the food chain.

Pyramids may be of three types: energy, numbers, and biomass. An energy pyramid shows a decreasing amount of energy available to each successive trophic level. This pyramidal shape is, of course, in accordance with the fact that only 10 percent of the energy at each trophic level is available to organisms at the next higher level. A pyramid based on the number of organisms at each trophic level also reflects energy loss, as does a pyramid based on biomass. Because only 10 percent of the energy at a given trophic level is available to the next higher level, food chains are usually short—usually not more than four or five links—and the number of organisms at each lower level must be greater than that of the organisms at the next higher level.

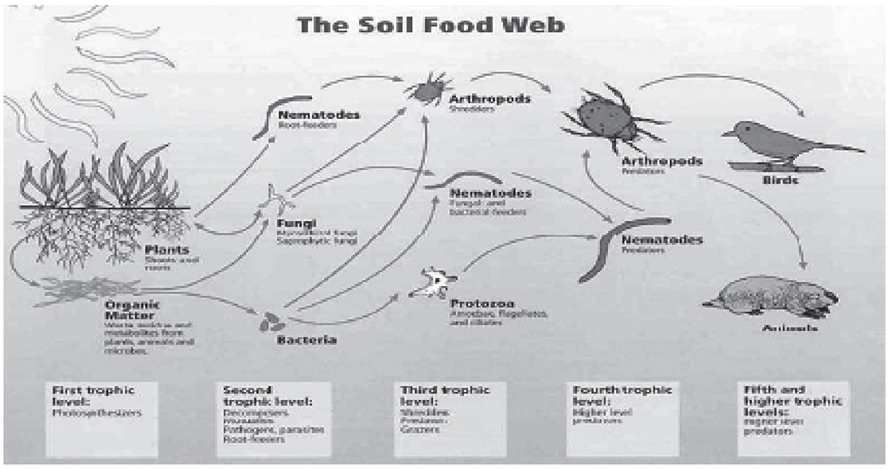


Image from:soils.usda.gov/…/soil_food_web.htm

An example of this could be found in a forest where green plants receive their energy from the sun. Primary consumers might include insects, mice, and rabbits. Secondary consumers could be birds and snakes, while tertiary consumers include wolves and owls. Note that owls are birds—a complex food web! Omnivores (like us) should be mentioned because omnivores circumvent the traditional notion of a food chain because they consume organisms from multiple levels.

Practice Questions:

1. How does the flow of energy through an ecosystem conform to the laws of thermodynamics? Be sure to discuss its origination, transformation, and utilization.

   Ecosystems conform to the laws of thermodynamics. The first law of thermodynamics states that energy is conserved; that is, energy cannot be created or destroyed, but it may be converted from one form to another. An ecosystem is a closed system that receives energy from outside sources; although there may be other sources, students have studied electromagnetic radiation from the sun. The organisms making up the ecosystem transform this energy into useful forms for storage and later utilization. Students study photosynthesis as a transformation process producing glucose (food), which may then be accessed as an energy source for the organism. The second law of thermodynamics states that some energy is lost as "useless" energy. Therefore, energy enters the system; is converted to food, which is stored by the organism; energy is used in normal metabolic processes; and energy is dissipated to the atmosphere during the normal living processes of the organism.

2. Green plants produce most of the oxygen in our atmosphere through a series of complex reactions. Name and describe this generalized reaction.

   Green plants produce most of the oxygen in our atmosphere by photosynthesis. The generalized reaction for this process is often referred to as "the light reaction."

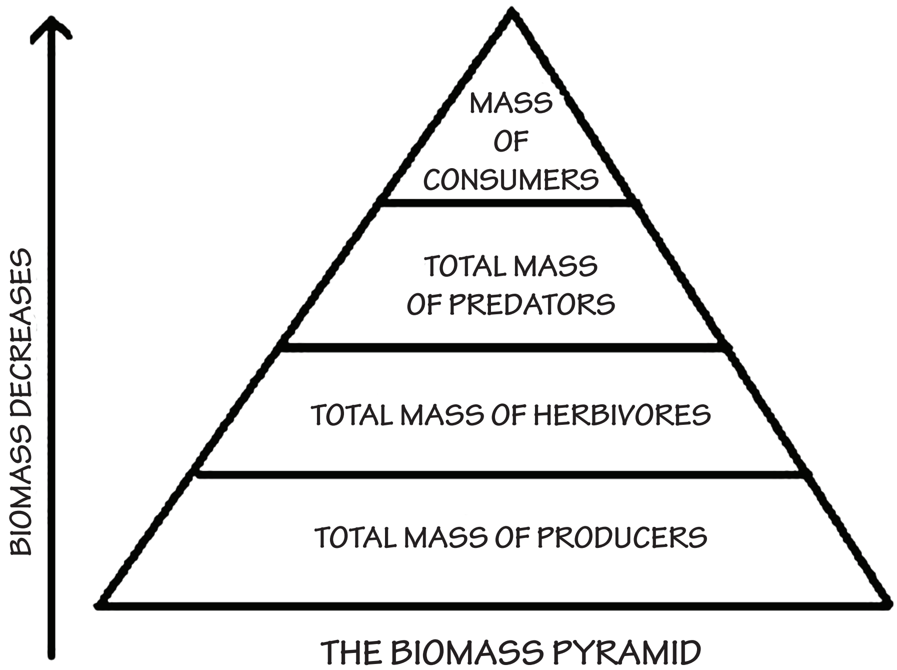
$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

carbon dioxide — water — glucose — oxygen

3. What is the role of ATP and NADPH in metabolism? What effect does the amount of light have on the metabolism of green plants?

   Green plants are able to make food by producing ATP (a carrier for energy) and NADPH (a carrier for electrons used in the synthesis of glucose) in their chloroplasts, which then reduce carbon dioxide and water to form a carbohydrate (glucose) only in the presence of sunlight and chlorophyll.

The amount of light available is critical for this process (photosynthesis) to occur.



4. Identify the structure shown above—be specific! What factors limit the steepness of the sides of this structure? Explain in detail.

   The diagram shown above may be a biomass, energy, or numbers pyramid by trophic level. As one moves higher on the pyramid, there is a decrease in biomass, energy, or numbers. Specifically, at the base level, stored energy, mass, or number of producers is greater than at the next level above. This decrease continues at each trophic level, culminating in the apex of the pyramid having the least biomass, stored energy, and/or quantity of individuals present.

5. A temperate deciduous forest contains the following organisms: oak tree, pine tree, grass, mouse, rabbit, crow, hawk, mushroom, dandelion, beetle, snake. Construct a food web using at least five of these organisms. If one of the organisms used in your web becomes unavailable, discuss what possible effect this would have on the web.

   There are numerous possibilities of a food web such as: grass-mouse-snake-crow-hawk. If one of the organisms becomes unavailable, the web changes to reflect the change. The most critical factor is at the lower levels of the food chain. If the producer (in this example, grass) becomes *unavailable, the next level (in this case, the mouse) will require another food source or a move to a different location. Otherwise it will starve.*

6. How would a food web differ in a different biome? To answer this part of question 5, select a different biome and create a food web.

   Different biomes have characteristic organisms present. You would not find a whale in a desert. It is important that the student name appropriate organisms for the selected biome and indicate a fitting food chain.

7. Each week, an owl must eat an average of five mice weighing 10 grams each in order to survive. How much plant material would each mouse have consumed? Solve this problem, and include set up and units. Explain how this scenario relates to trophic levels. Assume that energy and mass are proportional with the same constant of proportionality for each of these organisms.

   It is estimated that only 10 percent of the energy at each trophic level is available to organisms at the next higher level. It is given in the above question that an owl must consume five mice per week (one owl = five mice x 10 grams/each) in order to survive. Entropy occurs and not all of the grass is converted to biomass. Assuming that a 10-gram mouse would convert only 10 percent of the plant material, each mouse would have to consume 100 grams in order to survive. The mouse utilizes some of this grass for normal living functions, plus releases some as waste material.

$$1 \text{ mouse} \times \frac{10\text{g(mouse)}}{1 \text{ mouse}} \times \frac{10\text{g(grass)}}{1\text{g(mouse)}} = 100\text{g(grass)}$$

   In this example, grass is at the producer level. It makes up the greatest biomass, it is the most numerous, and it has the greatest combined energy of the system. As herbivores, mice would make up the next trophic level, and have less biomass, fewer individuals, and less stored energy than the tropic level below it.

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Ecosystem Structure and the Role of Species Within Biomes

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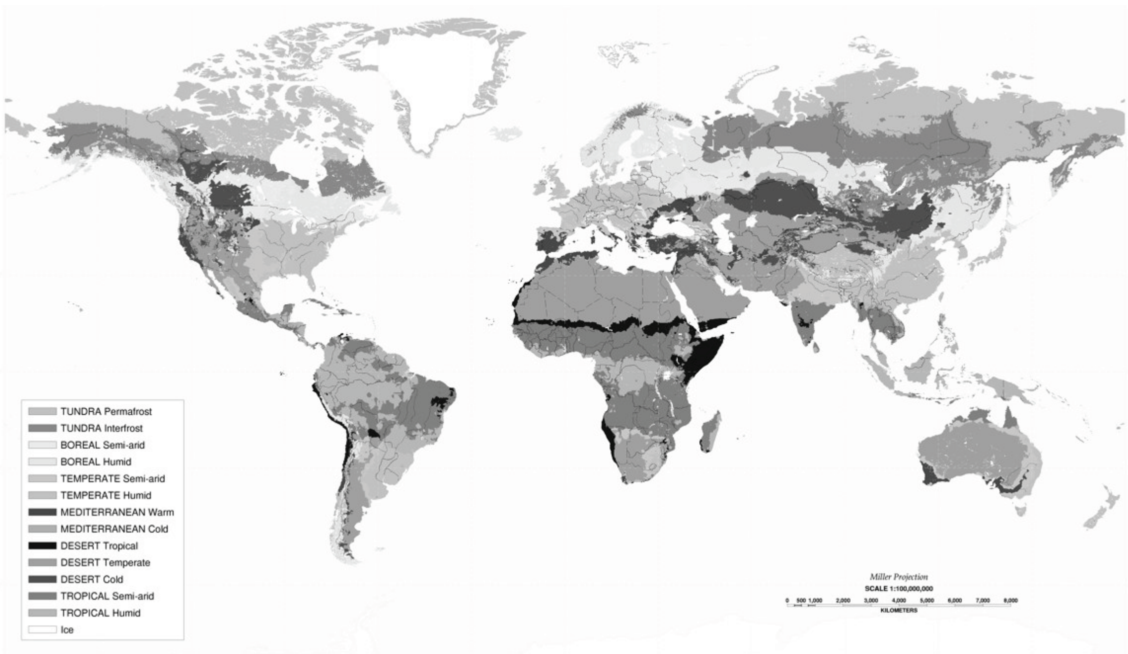
Introduction

A student of ecology should be familiar with the major biomes of the earth as illustrated below:



soils.usda.gov//use/worldsoils/mapindex/biomes

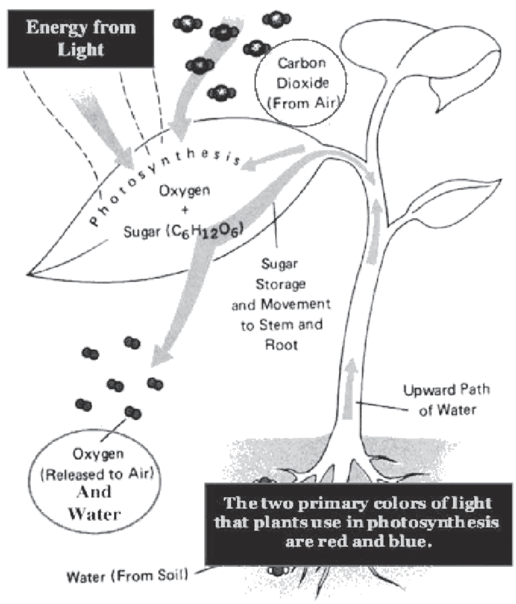
The main biomes include the polar regions of arctic tundra, taiga (boreal forests), temperate forests and grasslands deserts, and tropical forests and grasslands. There are also many different freshwater and marine biomes. For every biome there are unique abiotic and climactic conditions that support different organisms, from bacteria, fungi, and protists to plants and animals. The specific plants that can grow in a particular habitat are of utmost importance in determining what kinds of animals will be present as well, since the plant species support the animals.

Plants and animals interrelate in intricate and myriad ways. For example, plants may rely on animals, such as birds, insects, and rodents to carry pollen and fertilize seeds. The animals in turn use plants for shelter, nesting sites, and places to hide from predators or search for prey. Plant roots help hold soil moisture, nutrients, and particles against erosion, thereby reducing silting and fluvial deposits in streams and ponds whose turbidity would otherwise increase. This erosion control increases the depth of penetration of light, likely increasing the rate of photosynthesis and primary productivity.

Primary Productivity

Primary productivity is the fabrication of carbon compounds through photosynthesis or chemosynthesis by bacteria, protists, and plants. Such organisms contribute the sugars, lipids, and other building blocks for all other consumers in the trophic levels above the producers in a food web or energy pyramid. The organisms in a specific biome that support the rest of the organisms in this way are called *primary producers.*

The ultimate source of the energy producing this organic fuel is sunlight. Raw materials of carbon dioxide gas and hydrogen from water combine to form the organic compounds, releasing oxygen from water into the atmosphere. *Gross primary productivity (GPP)* represents the rate at which producers can convert solar energy into biomass. *Net primary productivity (NPP)* represents the rate at which producers make and store photosynthetic products, but also takes into account the needs of the producers to use some sugar for their own energy requirements. Therefore, one must subtract the rate at which producers use some of their stored energy through aerobic cellular respiration. The general formula for calculating the available biomass in the form of high energy organic compounds is: *GPP - respiration rate = NPP.* These productivity values are often given in mg/L/day or may



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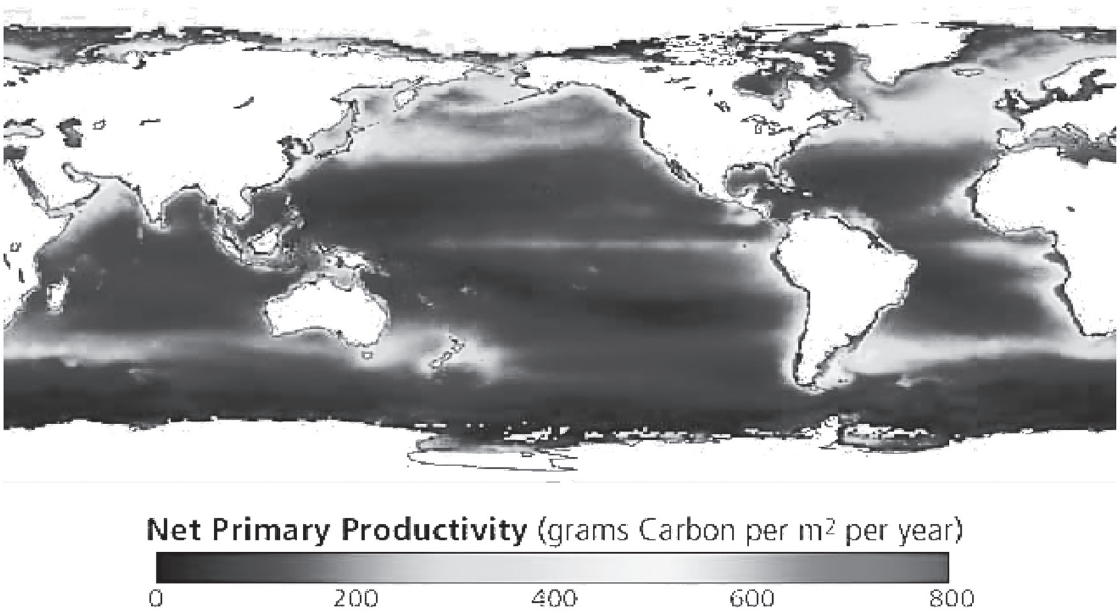
be expressed in energy units, such as kilocalories or kilojoules per day. Average net primary productivity in kcal/m^2/yr is sometimes referred to as *natural capital.*

Various ecosystems and biomes of the earth show different rates of GPP and NPP. In terrestrial environments, tropical rainforests, swamps, and marshes have the most chlorophyll and other photosynthetic pigments that are often visible in satellite images and have the highest productivity rates, whereas deserts and polar regions have the lowest rates. In aquatic environments, salt marsh estuaries have the highest rates of NPP per square meter due to the nutrient-rich, detritus-filled waters that support dense *Spartina* grasses or mangroves. Oceanic productivity rates are the greatest overall, due to the fact that marine phytoplankton are efficient at various depths because of their different light-absorbing pigments and the vast number of these producers worldwide. Equatorial marine environments are often more productive than polar regions, and shallow coastal waters are more productive than deep, colder waters. Productivity is monitored by satellite images from which chlorophyll concentrations can be observed, as illustrated below.



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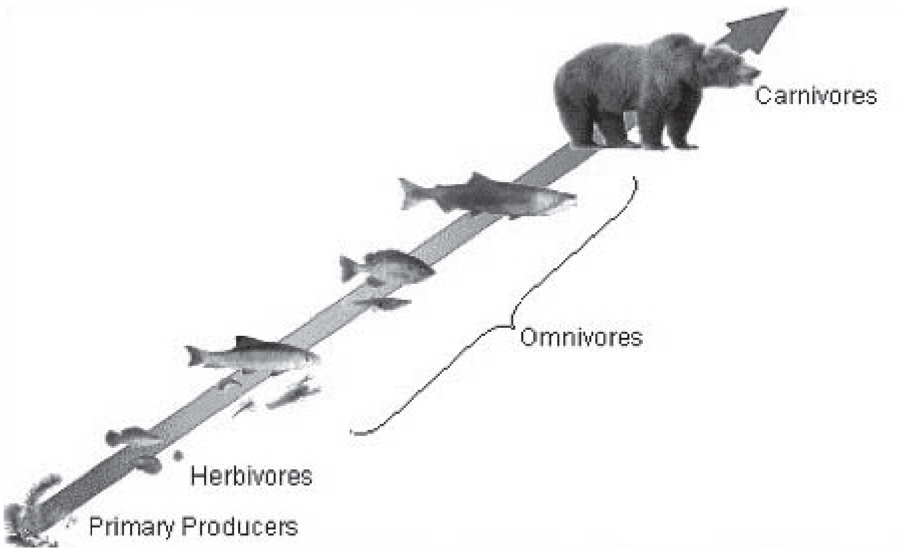
Roles of Species in Ecosystems

Within an ecosystem, certain *keystone species* play a crucial role in maintaining the biotic structure. Removal of the keystone species may have dramatic consequences for the overpopulation of herbivores, eventually decreasing the primary productivity of the ecosystem, resulting in overgrazing in certain terrestrial biomes. For example, in rocky intertidal zones sea stars feed on plankton-eating bivalve mollusks that would otherwise grow uncontrollably and cover the area. Because sea stars keep the population in check, a variety of other organisms like barnacles, anemones, and other invertebrates often flourish in the tidal area. A terrestrial example is the African elephant, which helps maintain the grasslands and savannahs. Without the elephants trampling the area and pulling up small trees and bushes for food or without some other animal to take on the elephants' role in this ecosystem, shrubs and bushes would create too much shade for the grasses to grow. The grasslands thrive in direct sunlight and help hold the soil with their roots. Normal grazing animals only eat the leaves and leave the roots intact. With fewer grasses, the organisms that eat the grass, such as antelope, die off due to lack of food reserves, ultimately affecting the number of predators, such as lions, who eat the grazers. Additionally, elephants are important in distributing seeds of trees they eat, and many trees species are lost when elephant herds are destroyed.



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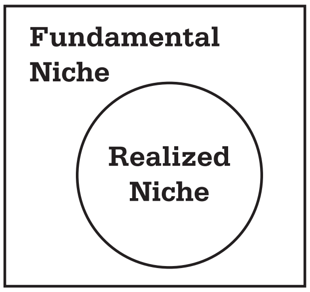
Indicator species are those that provide information about overall equilibrium and health of an ecosystem. Birds are used as indicator species because they are found everywhere and respond quickly to environmental changes; this is one reason the canary was often used when miners went deep below the earth's surface to show the effects of toxic gases or decreased oxygen levels. Oysters play this role in a salt marsh environment because as filter feeders, any toxins in the water would likely build up in the tissues quickly, and populations of these organisms may rapidly decline due to fluctuations in salinity, temperature, and sediment turbidity. Even *Escherichia coli* levels in aquatic ecosystems and soils can be considered indicator species and readily tested for and compared to EPA standards for water quality. *E. coli* is one of several bacterial species considered normal flora in the colon of mammals. In humans, it is necessary for the synthesis of vitamin K and proper digestion and excretion of bile salts. Some strains, however, are potentially lethal, and *E. coli* O157:H7 is a leading cause of food-borne illness. Clearly the levels of this microbe would signify the health of an area, particularly in the oyster populations in slow-moving tidal creeks that would have a propensity for filtering and collecting high levels of bacteria within their viscera. Another indicator species often used in terrestrial forest studies and pollution assays are lichens whose tissues are also quick to trap air and water-borne toxins and heavy metals.

Introduction of *exotic* or *nonnative* species has played a role in the exclusion of native species because they lack normal predator control or other limiting factors. These species are known by many descriptive terms including *nonindigenous, introduced, alien, transplants*, and *invasive.* Some exotics were introduced by wind, water, or other animals, but often they are brought to an area by humans. They can be devastating to the environment, degrading the normal habitats, reducing biodiversity, altering normal population genetics, and introducing alien diseases to the existing plants and animals, including humans. Not all nonnative species are harmful, and certain ornamental plantings may actually increase biodiversity, but the overall effects are usually detrimental. For example, zebra mussels introduced from Eastern Europe into the Great Lakes through the ballast of ships grow exponentially, clogging up waterways. Other common examples of introduced species that grow unchecked without natural predators include cane toads brought to Australia from Hawaii, kudzu vines from Asia, and armadillos and fire ants from Mesoamerica, which now thrive across much of the southeastern United States. Non-native species can be especially disruptive on island habitats with limited resources. This unchecked damage is certainly not a new phenomenon, and many historical accounts describe the deadly transmission of the measles virus and rodents by the early white settlers to Hawaii, as well as smallpox virus transmission to Native Americans by the Lewis and Clark expedition or by Pazzaro to the Incas, wiping out entire tribes and civilizations.

Niche Structure

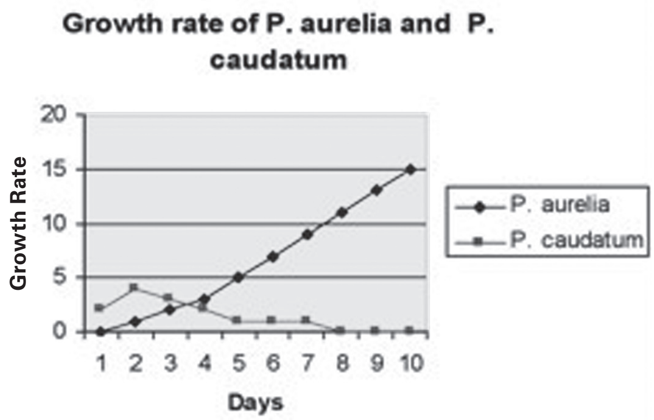
Individual species are usually adapted for a particular *habitat* and *niche* within a complex system. There are many abiotic and biotic *limiting factors* in species survival, including light, temperature, nutrients, gases, habitat space, water, wind, latitude, altitude, soil type, population size, and genetic diversity. The habitat refers to the specific geographical space in which an organism lives, including the limiting factors, while the niche represents the role of the organism in a community. In 1958 *G. E. Hutchinson* suggested that the niche could be modeled as an imaginary space with many dimensions. Each dimension or axis would represent the range of some environmental condition or resource that is required by the species. The niche of a plant might include optimum ranges of temperatures, light, humidity, and essential nutrients that it requires, while the niche of an animal could include the ranges of temperature, food sources, and predators. Different species can hold similar niches in different locations, such as the fact that seagulls along a beach and pigeons in a city both scavenge for food, or that different species of grass from grasslands of Australia or Africa provide the ground cover in North American prairies. Additionally, the same species may occupy different niches in different locations, organisms can assume a new niche when another organism dies out, or they take over a niche when introduced into a new habitat as in the case of nonnative species.

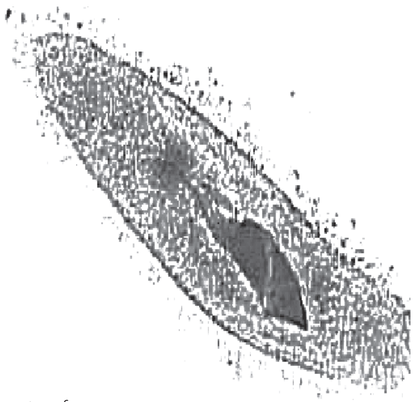


Niches may be categorized as either a *fundamental niche*, which is the full potential role of the organism and sometimes referred to as the "profession" of the organism; or a *realized niche*, which is the portion of the fundamental niche that is fully occupied by the organism when one takes into account interspecies competition and predation as illustrated.

Resource partitioning refers to evolutionary change in species in response to selection pressures from interspecies competition. Species may avoid competition by partitioning resources and habitats among themselves, and the degree of coexistence in the natural environment suggests that there is less competition in some areas. Common examples of resource partitioning include unique species of birds that forage on the same trees but obtain different foods such as berries and nuts or insects. These species often divide up the insects into different kinds by living at various vertical distributions in the same tree in a spatial microhabitat. In tropical rainforests, several different species of small anole lizards divide up the insect food population by living in different places within this same area.

Niche overlap occurs when resource requirements by at least two species are shared; however, when organisms do not partition their food, shelter, and other resources, natural selection pressures through competition or sexual selection may ultimately lead to the extinction of a species. This *competitive exclusion principle* of community ecology explains that two species that compete for the same resources cannot stably coexist when the conditions remain constant. One of the species will have an advantage over the other that either leads to its extinction or an evolutionary shift of the other species into a different or new niche in order to survive. A classic laboratory experiment of the competitive exclusion theory was conducted by the Russian biologist G. F. Gause, who grew two species of *Paramecium (aurelia and caudatum)* in individual cultures and then together. Both species grew exponentially and thrived when grown alone, but *P. aurelia* was the only successful species when the two were combined, thus illustrating the concept of exclusion as seen below.
A species' niche can be described as *generalist* or *specialist*. The generalist organism





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has the advantage of being able to eat a wide range of foods within a range of habitats, and its main problem is competition. The American alligator is an example of a generalist. A specialist has a very narrow range of habitat and diet, but often does not have as much competition. A giant panda is a specialist whose main concerns are predation and loss of habitat by human activities.

Finally, scientists often study the biodiversity of an area by conducting field sampling and using the Shannon-Weiner Index. The number of species in a biological community is termed *species richness, N*. For example, the number of species in a coral reef in Hawaii has greater species richness than grasslands of only a few species. *Species diversity* takes into account the abundance of a species as well. If a community is composed of very few species, or if only a few species are abundant, then species diversity is low. High species diversity indicates a complex community, with increased species interactions that have more energy transfer (food webs), predation, competition, and niches. *Evenness* is an expression that describes when species are equally abundant within the test area.

Activity 1: Introduction to habitats and species diversity

I. Purpose

The purpose of this investigation is to expose students to two different habitats that can be easily accessed, one having been regularly mowed and the other where the underbrush is heavy and diverse. Students should be able to understand the concepts of biodiversity within a small area while also learning field techniques to study different abiotic factors such as temperature and soil characteristics. Students will also design their own lab report or presentation of their results.

II. Procedure

Students should write a hypothesis about what they expect to see in the two different kinds of habitats before they go outside. Be sure to have students wear appropriate clothing, sunscreen, and bug repellent if needed.

Obtain the following: a meter square made from PVC pipe or a single meter stick to form a quadrant, soil temperature probe, soil pH meter, soil moisture meter, small trowel, bags or jars for collecting specimens, an insect/butterfly net, a camera if desired, clipboard, paper, and pencil. Field manuals of local vegetation and animals will be helpful.

Place the meter square in a "new field" that has been mowed regularly, and conduct the tests listed below. Then perform the same tests in an "old field" that has been permitted to grow for several seasons. Around a school the soccer or football field works nicely for a new field, and an area near a ditch or under a power line easement can usually be found nearby to serve as the old field.

Record the following:

- types of plants
- average height of the plants (measure a representative sample and take the average)
- three soil temperature readings and average
- three soil pH measurements and average
- three soil moisture readings and average

1. Collect a small sample of soil and bring it back to the lab using the trowel or an auger. This may be examined with a microscope or by using a Berlese funnel to extract macro invertebrates. Animals collected may be placed in alcohol or frozen for later study.
2. Dig a small hole in the soil with the trowel or auger. Sketch and describe the soil horizons or layers, if any.
3. Collect insects with the net if available and classify if possible. Photograph these and release, or collect as desired.
4. Students should construct data tables, charts, and illustrations to collate and display the results, and they should write a conclusion based on their earlier hypothesis about the differences between the two habitats.

Activity 2: Measuring Primary Productivity in an Aquatic Ecosystem

I. Purpose

The purpose of this investigation is to observe and calculate gross and net primary productivity, to describe how photosynthesis and respiration are related to primary productivity, and to perform an experiment to test the effects of nutrient enrichment on an algal culture. Students should understand the importance of production in the flow of energy in the ecosystem as it relates to species interactions in the food chain.

II. Procedure

Day 1:
Obtain three BOD (biological oxygen demand) bottles and a dissolved oxygen test kit. Rinse bottles out with spring water. Screw-top test tubes will work for the BOD bottles, but they need to be completely filled.

- Obtain 800–1000 ml of the algal culture using a 1000 ml beaker. Chlorella works well for this.
- Label three BOD bottles as follows: **Dark, Light, Enriched**
- Put an identifying mark on the bottles.
- Carefully fill and cap the first two BOD bottles (**Dark** and **Light**), making sure not to agitate the algal culture and not to allow any air bubbles into the BOD bottles.
- Wrap the **Dark** bottle completely with aluminum foil so no light can enter. Respiration will occur in this bottle.

- Put in 5 mL of a fertilizer solution into the **Enriched** bottle. It should contain nitrogen and phosphorous in a bio-available form. The N is in nitrate or ammonium ions, and the P is in phosphate ion. Miracle Grow or Planters works well for this.
- Carefully fill the **Enriched** bottle with the algae culture and gently agitate to mix the solution and the culture together.
- Place all three of the BOD bottle on the shelf of a grow stand, or by the window.
- Take a sample of the original algae culture, test the initial dissolved oxygen, and record this value in PPM or mg/L.

Day 2:

- Determine the dissolved oxygen (DO) for each of the three BOD bottles.
- Record the data in the table below, collect the data for each group in the class, and record in the class data table. Students may construct their own data tables if preferred.

Data Tables

Group Data

	DO (ppm = mg/L)
Initial	
Dark	
Light	
Enriched	

Class Data

	DO (ppm = mg/L				
	Group 1	Group 2	Group 3	Group 4	Group 5
Initial					
Dark					
Light					
Enriched					

Calculation of Gross and Net Primary Productivity:

Respiration rate (mg O2/L/day) = **Initial - dark** = ______________________________

Sample	Gross Primary Productivity (Light or Enriched-dark) mg O_2/L/day	Net Primary Productivity (Gross-respiration) mg O_2/L/day
Light		
Enriched		

Questions:

1. Define gross primary productivity (GPP) and net primary productivity (NPP).
2. Why is respiration rate important in the calculations?
3. What are the two environmental factors that greatly influence the rate of production by photosynthesis? Which of these appears most important in your experiment?
4. How can you account for variations in the class data?
5. Identify the most productive terrestrial and aquatic ecosystems in terms of NPP, and explain why they have this characteristic.
6. Define eutrophication and describe how this is illustrated in this experiment.

Activity 1: Teacher Notes

This simple activity can become an open-ended inquiry where students design their own tests and sampling methods. This activity is easy to perform in any school environment where there are sports fields that are regularly mowed, and areas that are somewhat overgrown with tall grasses and underbrush. Have students generate an experimental hypothesis and null hypothesis for this activity. Ask the students to write three-to-five questions they want to answer before they begin the field work, and then have them write three-to-five more questions that they want to answer when they return to the classroom.

Students should construct their own data tables for soils, plants, and animals they will find in their "old field" and "new field." These will be as varied as you permit. Upon returning to the classroom, let students construct histograms or spreadsheets of their data in order to quantitatively manipulate their results.

In general, "old fields" should have greater biodiversity of plants and animals, as well as darker, richer soil as a result of more leaf litter. The "new field" should exhibit more monoculture, with fewer species of plants and animals and less rich soil.

Activity 2: Teacher Notes and Sample Data

Data Tables

Group Data

	DO (ppm=mg/L)
Initial	8 ppm
Dark	5 ppm
Light	10 ppm
Enriched	12 ppm

Calculation of Gross and Net Primary Productivity:

Respiration rate (mg O_2/L/day) = **Initial-Dark** = ________3 ppm ____________________

Sample	Gross Primary Productivity (Light or Enriched-dark) mg O_2/L/day	Net Primary Productivity (Gross-respiration) mgO_2/L/day
Light	10–5 = 5 ppm	5–3 = 2 ppm
Enriched	12–5 = 7 ppm	7–3 = 4 ppm

Answers to Questions:

1. *Gross primary productivity (GPP)* represents the rate at which producers can convert solar energy into biomass. *Net primary productivity (NPP)* represents the rate at which producers make and store photosynthetic products minus the respiration rate, GPP-R = NPP.
2. Respiration rate accounts for the energy utilized by the photosynthetic organisms to maintain their normal metabolic processes and removes energy from what can be stored in biomass.
3. The two most important factors that contribute to primary productivity are available light and nutrients. The experiment should demonstrate that nutrients are more important than light in an overall aquatic ecosystem.
4. Class data will vary.
5. Tropical rainforests, temperate forests, and swamps are likely the most productive terrestrial ecosystems, while salt marsh estuaries and shallow coastal waters are the most productive aquatic ecosystems per square meter. All are productive due to high levels of chlorophyll and other accessory plant pigments that harness solar energy.
6. Eutrophication is the change that takes place in a stream, lake, or estuary after high amounts of nutrients, primarily nitrates or phosphates, are added. In this experiment, eutrophication is modeled by the enriched BOD bottle, which causes rapid algae growth.

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Evolution

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> "Each living creature must be looked at as a microcosm, a little universe, formed of a host of self-propagating organisms, inconceivably minute and as numerous as the stars in heaven."
>
> Charles Darwin, 1868

Evolution involves the change in gene frequencies within populations from generation to generation and can be depicted as a tree with millions and millions of branches. The branches that stop before the top represent 99.9 percent of all species that have lived on this planet *but* are currently extinct. The tips of the branches that actually reach the top represent those species that are currently alive and symbolize the biodiversity present on our planet today.

Evidence of Evolution

Often scientists will only start investigating an idea after developing an educated guess or hypothesis. This hypothesis needs to take into consideration all current knowledge and then predict the probable outcome of an upcoming experiment. After running multiple experiments in the laboratory or in the field (e.g., fossil hunters) to confirm or disprove the hypothesis, the scientist will publish the results. Other scientists around the world interested in the same idea may retest the hypothesis and then publish their results. After a significant number of scientists confirm the idea, a theory, *not a fact,* is developed that tries to mold all the outcomes into one coherent explanation of the data. Sometime in the future, there may be valid experiments that do not fully agree with the theory, consequently, the consensus is changed and the explanation is revised but only rarely rejected. Scientists have used the scientific method in a variety of ways to develop an explanation of the diversity and continuity of life, all of which support the theory of evolution.

Dating of Fossils

The Leakey family, Donald Johanson and his Institute of Human Origins, and various others have collected evidence for human evolution in for the form of fossilized remains. Fossils are evidence of past life that usually appear in layers of sedimentary rock. The fossils found in the top layers are from those organisms whose branches are closest to the top of the evolutionary tree, while those further down are from lower points on the branches. This method of comparison is called relative dating. Another method uses radioactive isotopes found in the fossils or the surrounding rock. Radioisotopes decay at a constant rate that is related to the half-life of the isotope. In an interval of time that is equal to the half-life, 50 percent of the atoms of the unstable isotope are transformed into atoms of another type. All living organic materials such as carbohydrates, proteins, and carbon dioxide contain a specific ratio of radioactive ^{14}C and stable ^{12}C carbon atoms. All living organisms maintain that specific ^{14}C to ^{12}C ratio due to the uptake of organic materials and growth. When death occurs, exchange with the environment ceases. When fossilized remains are found, the ^{14}C to ^{12}C ratio can be determined, allowing the calculation of the age of the material from the number of half-lives that have transpired. For example, ^{14}C has a half-life of 5,730 years, so if only one-fourth of the original ^{14}C is present in the fossil, two half-lives (or approximately 11,460) years have elapsed since the death of the organism.

Phylogenetic Relationships

Taxonomic classification involves organizing organisms into groups and giving them scientific names. Species initially were put into groupings based on superficial features, such as whether they swam, climbed, or were red in color. After Linnaeus (1707–1778), there was an emphasis on using more than one characteristic to decide in which taxonomic groups or taxa the species should be placed. Taxa are now developed using evolutionary relationships to illustrate close kinship between species.

Today, scientists use DNA and protein similarities to identify where and when branching in the evolutionary tree took place. Organisms that share large percentages of their DNA are closely related. All humans have essentially 100 percent identical DNA because *all humans* share *essentially all the same genes* with only small sequence differences that make each person unique (0.001 percent total difference). As the closest evolutionary branch to humans, chimpanzees have 98.5 percent similarity, while mice only share 92 percent of the same DNA. As the branches of the evolutionary tree get farther away, the genetic similarity decreases as seen in the

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fruit fly and yeast, who share on 44 percent and 26 percent of the genes found in the human genome, respectively.

Comparative Anatomy

One example of the interplay between taxonomy and evolution involves the use of comparative anatomy. Two of the methods for determining taxa involve identification of organisms with homologous structures and those with vestigial structures. An example of homologous structures can be seen in the similar bone structure in the forelimb of fairly closely related organisms, including humans, cats, whales, and bats, but not in the forelimb of a less closely related organism like the cockroach. Vestigial structures are those that are fully functional in some organisms, like the hips and legs of humans, while closely related organisms may only have remnants of those structures, as in whales or boa constrictors. In both cases, these organisms are related, but the degree of homology and amount of vestigial structures help determine how close they are in taxonomy and in the evolutionary tree.

In 1860, Charles Darwin told a friend, "Embryology is to me by far the strongest class of facts in favor of change of forms." In 1838, Karl von Baer developed his law of animal development, which states that structures present early in development are found in many animals, but structures that develop later in a species are not found in as many other species. Genes that are involved in early development are conserved, while those that make the species unique are turned on later during development. This process differentiates that species from its closest relatives on the evolutionary tree.

Causes of Evolution

Biological evolution occurs due to four independent factors that act synergistically. Mutations, genetic drift, the founder effect, and natural selection act together to cause changes many times greater than any of the individual factors. For example, the advantages of a mutation resulting in the ability to flee faster or better will only result in evolution if that organism survives, breeds, and passes on the gene *with the mutation* to the next generation. The first three will be discussed in this section, while natural selection or "the differential reproduction of individuals in the same population based on genetic differences among them" will be described in a section about Charles Darwin.

Mutations are any change in DNA that *may* result in change in RNA expression that *may* result in change in protein expression that *may* result in a phenotypic change, which is the change in appearance or behavior of the organism. DNA mutations may be chromosomal or point mutations that result in deletions, substitutions, inversions, or duplications. Silent changes involve base substitutions where a codon is changed without a change in the amino acid, thus resulting in no phenotypic change. Nonsense mutations cause a change in the bases such that a stop sequence is inserted before the end of transcription or translation, resulting in a loss of the expected protein. Mutations may also affect the activity, stability, processing, or regulation of proteins.

In a continuous population, genetic novelty or *gene flow* can spread locally and may or may not lead to speciation or the formation of a new species. Populations that are isolated from each other experience *genetic drift,* which occurs due to mutations that result from an increasing difference in the gene pools of the populations. Genetic drift may lead to new species, as evidenced by the discontinuous populations of the Kaibab and Albert squirrels on the North and South Rims of the Grand Canyon, respectively. Due to the interrupted, independent genetic flow caused by the geographical separation, the two groups of squirrels eventually drifted far enough apart *genetically* to became separate species.

When a new population is formed, its genetic composition depends largely on the gene frequencies within the group of first settlers. This sampling bias that occurs during immigration is known as the *founder effect*. The finches of the Galapagos Islands of Ecuador were some of the first birds to settle the islands, and the predominant birds on the island are the descendents of those finches. Likewise, Native Americans are genetically similar to Asians as opposed to Europeans or Africans, as the tribes that crossed over into the Americas during the Ice Ages had to originate near the Bering Land Bridge.

Charles Darwin and Natural Selection

Charles Darwin was born in 1809 into a wealthy English family. As a young man, he decided to follow in his father's footsteps by studying medicine, but after a short period of intensive schoolwork decided to try the field of theology, which soon gave way to an interest in botany. An influential professor at Cambridge encouraged the 22-year-old to sign up to sail on the *H.M.S. Beagle*. The *Beagle* and crew were slated to sail for three years surveying the South Seas, with most stops located in South America and the Galapagos Islands. Darwin's job as the naturalist on board was to collect and classify plants and animals. While on the Galapagos Islands, Darwin observed species that lived nowhere else in the world, such as the finches, giant tortoises, and marine iguanas. While sailing between stops, he read Lyell's *Principles of Geology,* which suggested that fossils found in rocks were evidence of animals. The observations on Galapagos and Lyell's suggestions guided Darwin to develop an idea about the origin of species. Darwin pondered these ideas for the next 20 years until Alfred Russell Wallace, who had similar ideas, approached him. In 1858, the two presented their findings at the meeting of the Linnean Society in London. Charles Darwin finished writing his book *On the Origin of Species by Means of Natural Selection,* which was published the following year.

The conclusions of the book were that species were not created in their present form but evolved from ancestral species, and that this evolution occurred by a mechanism Darwin called *natural selection*. Natural selection has five premises:

- Most species produce more offspring than can be supported by the environment.
- Environmental resources are limited.
- Most populations are stable in size.
- Individuals vary greatly in their characteristics (phenotypes).
- Variation is heritable (genotypes).

The underlining theme is that different individuals in the same population have varying degrees of success in reproducing *based on genetic differences.* Those with genetic differences that are suited to the current environment will successfully reproduce, have offspring, and pass on their genes. Those individuals whose genetic differences do not suit the current environment will die and will not pass on their genes. The distinction between the two groups of individuals is called *differential reproduction.*

Differential reproduction results in the predominance of certain genes and therefore certain phenotypes. Typical populations have a normal curve for each phenotype where some individuals have extreme characteristics, but most are between the extremes. *Stabilizing selection* occurs when under certain environmental conditions, the extreme phenotypes are not favorable, and therefore those individuals in the extreme region will die, and their genes do not continue in the population. *Directional selection* involves removal of the genes and individuals from one of the extremes, and therefore pushes the particular phenotype toward one end of the spectrum. By contrast, *diversifying or disruptive selection* somehow selects against those in the middle of the normal curve, therefore favoring the genetic variants of the extreme phenotypes.

Sometimes reproductive barriers exist that impede two species from producing fertile and/or viable offspring. This can involve prezygotic (fertilization of the egg by sperm) or postzygotic barriers. There are five types of mechanisms that deter the fertilization of the egg. The first involves temporal isolation, where breeding occurs at different times for different species—two different plants in which the stamen and carpal mature at different times, thus eliminating any possibility of natural fertilization. The second involves habitat isolation, where the two individuals live in different habitats. An example involves lions and tigers that live on different continents, but that under artificial conditions produce fully viable offspring. This hybrid is either a liger, which is a hybrid cross between a male lion and a female tiger, or a tigon, which is the hybrid between of a male tiger and a female lion (and is not as common). Certain groups have behavioral isolation where different innate behaviors result in little or no sexual attraction between species. The mating ritual of the blue-footed boobies involves their showing off their blue feet. Mechanical isolation prevents reproduction because the reproductive structures are not complementary. Lastly, gametic isolation involves an inability of the sperm to fertilize the egg, perhaps because the egg's sperm receptor does not allow attachment of sperm to ova.

There are several types of postzygotic barriers. Hybrid inviability involves hybrid zygotes that do not mature or adults who do not sexually mature. Hybrids of sheep and goats die in the early stages of embryonic development. The mule is an example of hybrid sterility where the hybrids mature to adulthood but are not able to produce functional gametes. Hybrid breakdown is more common in plants than animals and involves offspring of hybrids that are weak or infertile. Cotton plant hybrids will die before or shortly after germination, or form fragile plants that do not survive.

Speciation

One of the definitions of speciation originated in the early twentieth century through the independent work of David Starr Jordan and Ernst Mayr. They first stated, "Speciation begins when a single species becomes geographically separated into two populations. Individuals cannot travel between the populations, preventing the two populations from interbreeding." Second, "because the two populations cannot exchange genes, and because they may be subject to different environmental conditions, they slowly evolve differences." Third, "eventually the two populations become different enough that they do not interbreed even if they come into contact (in other words, they are 'reproductively isolated'), and are therefore separate species." There are occasional problems with this definition as evidenced by the ring species, such as the herring gulls. Starting in Great Britain, the white gulls will mate with gulls from eastern North America and so on westward around the Arctic until Norway. Here the gulls have black markings and will not breed with the white gulls of Great Britain.

The two theories that attempt to explain speciation during evolution are the phyletic gradualism model and the punctuated equilibrium model. The major difference between the two is how they interpret gaps in the fossil record. Gradualism indicates that mutations, phenotypic changes, and speciation are gradual and that the fossil record gaps are simply due to the difficulty in finding fossils. Punctuated equilibrium says that over long periods of time, mutations simply accumulate but do not cause any drastic phenotypic changes resulting in speciation because niches may have become unavailable. Then due to some short-term change in the environment these mutations are expressed as new species, thus accounting for the lack of transitional fossils in many phylogenic branches. Charles Darwin was the author of the phyletic gradualism model, while the paleontologists Niles Eldredge and Stephen Jay Gould introduced the idea of punctuated equilibrium in 1972. Evidence supporting the punctuated equilibrium model can be seen in the huge increase of species at the end of the Mesozoic period and at beginning of the Cenozoic period.

There are many plot lines in these theories of evolution. One involves adaptive radiation in which numerous novel species form branches from a common ancestor introduced into new and diverse environments. This phenomenon is a subplot of the founder effect mentioned earlier. This can be seen in the multitude of species that have radiated from the original finches as seen in the Darwin finches in the Galapagos or as the honeycreepers in Hawaii. Another plot line involves two distinct evolutionary branches that fit into the same niche. Convergent evolution occurs when two unique species develop similar characteristics under similar conditions in completely different locations. Examples include the large flightless ostrich of Africa, the emu of Australia, the sidewinder of the Mojave Desert in the United States, the horned viper from stony deserts in the Middle East region, and the development of more than five different mechanisms of vision. A third plot line involves the intertwining of evolutionary branches such as the trunks of ficus trees. Coevolution of symbiotic organisms occurs when one species acts as a selective force on a second species, inducing the selection of an adaptation that acts as selective forces on the first species. Examples include predator–prey relationships such as the wolf and the moose, the mutualistic relationship found in acacia trees and their ants, and yucca plants and moths. The final plot line involves extinction that will open niches for new species. Extinction occurs when a species ceases to exist, either globally, as in the case of the passenger pigeon and the dodo, or locally, as in the 1916 killing of the last grizzly bear in the Los Angeles National Forest.

Symbiosis

Symbiosis is probably one of the most misunderstood words in science. Symbiosis was first defined in 1879 by H. A. DeBary as "unlike organisms living together," whether it involves positive, negative, or neutral interactions. Organisms that are in these relationships have coevolved so that their relationship is the most beneficial or least harmful as possible. The first type of symbiosis to be discussed will be mutualism, which is the term that actually means that both species benefit. Commensalism indicates that one species benefits while the other is unaffected. Parasitism occurs when one species benefits and the other is harmed and/or killed. Competition occurs when neither species benefits. The last type of symbiosis involves the predator–prey relationship that is positive for one species only and will be discussed in more detail in the next section.

Mutualism is a positive interaction between individuals of different species in which both partners benefit. Some of the advantages of forming a mutualistic relationship include increased birth rates, decreased death rates, and increased carrying capacity. Obligatory mutualism occurs when two species have coevolved and *cannot* survive without the presence of the other species. Examples include the lichens, which are a combination of fungus and algae; and the yucca moth, which only eats the seeds of the yucca tree; the only pollinator of tree is the moth. Facilitative mutualism involves organisms that can be mutualistic but can live independently as well. The ants that protect plants from predation while deriving nutrients and a habitat are an example.

Commensalism is a term employed in ecology to describe a relationship between two living organisms where one benefits and the other is not significantly harmed or helped. One example includes organisms that attach themselves to another for transportation, such as the eyelash mite, which feeds on the dead skin of humans; and remora, which attach themselves to sharks and dine on the leftover scraps. A second type involves using another organism for housing, such as epiphytic orchids, which grow in crooks of trees; or birds that nest in trees. The last includes hermit crabs that use cast-off shells; this type involves an organism that uses something the first created even after the death of the first.

Competition occurs between members of separate species (interspecific) or between members of the same species (intraspecific), but in both cases neither species nor individuals benefit. The competition may occur due to exploitation in which the individuals share the same limited resource(s) or due to fighting, exhibition, or other damaging behavior. Thus the species is not able to fill its potential *fundamental* niche, leaving it with a less fulfilling *realized* niche. An example involves wolves and coyote that live in the same territory, with the wolf usually prevailing over the coyote.

Parasitism occurs when an organism spends a significant portion of its life history attached to or inside a host organism. Under normal parasitic symbiosis, the two organisms have coevolved such that the parasite will not harm the host by taking too many nutrients. These parasitic relationships include tapeworms, flatworms, and roundworms—which are commonly found in most animals, including humans. Parasitoids represent the type of parasitic symbiosis that ultimately kills and consumes the host. Parasitoids are generally limited to arthropods such as parasitic wasps, which control populations of agricultural pests.

Predator–Prey Relationships

The predator–prey relationship is a type of symbiotic relationship in which one organism benefits while the second has a negative experience because all or part of it is eaten. The interacting species have coevolved such that any mutation in one leads to a positive adaptation in the second or that species may go extinct. Predators that kill their animal prey include carnivores and omnivores, while herbivores rarely kill the plant prey because they usually only remove parts of the plant. Predators have adaptations that allow them to detect, recognize, capture, and eat their prey. Animal prey have adaptations that allow them to avoid detection, avoid capture, disrupt capture, or develop methods to avoid being eaten, while plants have structural or chemical defenses against herbivores. Due to chance there will always be random groups of prey that predators do not find.

All or part of the predators' sensory system can be used to *detect* prey. The sensory system includes visual, olfactory (smell), auditory (hearing), and somatosensory systems (touch, pressure, etc.). Some predators use their senses to directly detect prey, while others use indirect clues. Vision in many predators is highly evolved, as evidenced by binocular vision, where the field of vision for each eye overlaps in the front. This adaptation gives the predator better depth perception, helping it catch prey that is moving at high speeds. Blue jays have been found to have a mental shape of their prey, which allows them to distinguish prey from nonprey. The kestrel, a type of falcon, is able to detect the feces and urine of its prey, which reflects ultraviolet light that the predator can see. Mosquitoes can detect higher-than-normal CO_2 concentrations 30 meters from the host and will fly up the concentration gradient until seeing or detecting the heat from prey.

Capturing the prey involves stalking, catching, and killing the prey by neck bite, strangulation, evisceration, toxin, or some other method. Carnivores may stalk their prey stealthily, as with lions, or by speed, as with greyhounds. Animals with a longer foot, where less of the foot touches the ground, are faster and longer runners. The fastest animals, like horses and deer, have very long feet and walk on the tips of their toes, which are usually protected by hooves, or on the ball of their feet, as in the case of wolves. Crypsis, which is the ability of an organism to avoid being observed, can help to make stalking a success. Part of the capture can include *passive* methods such as that attempted by the benthic anglerfish to catch "Nemo and Dory" in the film *Finding Nemo* and by spiders using webs, or by *active* methods such as methods used by tarantulas and grizzly bears. Active capture can involve *individuals* running down their prey, as with the cheetah; silently inviting the unsuspecting victim, as with the Venus flytrap; or using *cooperation*; as found with packs of wolves, prides of lions, and flocks of white pelicans. Examples of killing methods include the neck bite to suffocate, which is used by lions; strangulation to suffocate, which is used by the boa constrictor; evisceration, which is used by the wild dogs of Africa; or employing a toxin that causes immobility, which is used by black widow spiders.

Carnivores such as the cheetah have long stabbing canines and sharp knife-like teeth for cutting flesh. Omnivores such as humans have a combination of sharp cutting teeth and flat grinding teeth. Herbivores such as the pronghorn antelope have flat rasp-like teeth for grinding up plants. Prey can be eaten in pieces or whole. Grizzly bears use teeth to tear into the animal, while raptors use claws and beak. Many reptiles such as constrictors and amphibians such as cane toads eat their prey whole.

Prey animals have adaptations that allow them to avoid detection and capture, and/or methods to avoid being eaten. Crypsis is the ability of an organism to avoid observation through the use of camouflage, nocturnal behavior, living underground, or aposematism, or by some form of mimicry. Camouflage allows members of a species to blend into the background using combinations of color, shape, and pattern. Background camouflage includes the environment (spots on baby deer, stick bugs, or preying mantises that resemble leaves); other organisms (stripes on zebras or schools of fish) confuse predators. Some organisms such as chameleons or octopodes have a limited ability to change their color or patterns to match the background.

Another method used to *avoid detection* is called aposematism, and it is actually anticamouflage. Certain organisms either taste bad (monarch butterflies), are poisonous (milkweeds, harlequin toads, and poison-dart frogs), have chemical defenses (skunks), or are able to physically harm the predator (wasps or coral snake). These unpalatable or noxious species have distinctive coloration or patterns that indicate a warning signal to potential predators. Mimicking the warning signal is an effective method of avoiding predation. Mullerian mimicry involves several unpalatable species that have similar coloration, such as yellowjacket wasps and bees, or viceroy and monarch butterflies. Batesian mimicry involves trickery, employing false features that appear to be aposematism. Examples of this mimicry include the Io moth, which appears to have owl's eyes on its wings; the poisonous coral snakes and the mimicking king snakes; or octopuses that are able to change coloration to look like predator fish.

Prey species also have many avenues to avoid being capture and eaten. Unlike the predator that has binocular vision, prey animals have eyes that face sideways, with only a small area of overlap in each eye's field of vision. This adaptation allows the prey animal to see almost all the way around its body, maximizing its ability to stay away from the predator. The pronghorn antelope or Thomson's gazelle uses speeds of over 90 kilometers per hour to avoid capture. Sometimes, however, gazelles start to run, but will then slow down and stot. Stotting is the high jumping into the air with back legs held straight back. Predators often give up on the hunt after being harassed by stotting.

Porcupines and hedgehogs have obviously made the point that capturing them as a meal will be difficult. Mobbing occurs when a group of prey animals (usually birds) attack the predator, such as when crows cooperatively harass hawks. Mobbing occurs most often in species whose young are frequent victims. The prairie dog (rodent family) and the meerkat (mongoose family) are examples of convergent evolution in which two social, subterranean dwelling critters have an altruistic lifestyle. Both use sentries that guard while the others search for food, and if any danger is spotted, warning barks send the furry varmints to the closest entrance.

Plants have also evolved methods to prevent ingestion. Mechanical interference occurs in cactus and other plants with thorns, spines, prickles, or sharp leaves. Edible portions of plants may not be accessible or easily found by herbivores, as seen in the canopy layer of the rainforest. Certain plants protect themselves through the use of toxins that kill, repel, or reduce their digestibility, such as lily of the valley, oleander, or jasmine berries. Grasses and similar plants have the ability to recover from the herbivore-induced damage because the vital portion of the plant is not destroyed; the herbivore eats the nonessential portion of the plant. Many plants, however, actually invite herbivores to eat portions, such as the fruit, that may then be instrumental in dispersal of seeds. Some plants, like acacia trees, will host organisms, such as ants, that discourage the presence of the herbivore.

Predator–prey symbiosis is not always a win–lose situation. Predators have a positive impact on the populations of prey by culling the very old and sick, and removing the very young. This removal keeps the population from overshooting the carrying capacity and therefore destroying the delicate balance of the prey with its source of food, whether it is plants or the sun. Animals, whether they are herbivores or carnivores, may spread seeds after they stick to their fur. Herbivores also increase the fertility of the soil due to passing of digested material or through their death and decomposition.

Activities

A. Stand-Up Adaptation

Fast and easy – 10 minutes maximum

1. Procedure

- Have everyone in class stand
- State characteristics of members of class

2. Examples

- All ladies under or over a given height
- All gentlemen under or over a given height
- Certain colors of eyes
- Cavities, etc.
- Indicate that an environmental event has deemed that characteristic unfavorable
- Tell them they have died and must sit down
- Continue until only two-to-three males and two-to-three females are left standing

3. Question/statement examples

- Characteristics exist before the selection process starts
- Only those that survive can reproduce and pass on their genes
- Obviously, if dead, no reproduction, and therefore no genes are passed on
- May be occurring now with HIV
  - HIV recognizes and attaches to a set of proteins on the surface of the CD-4 or Helper T-cells. In a small portion of the human population one of these proteins is absent. Although it does not affect the immune function of the cell, it does prevent the HIV from attaching to the cell. It is thought that this may have been an adaptation from survivors of either the bubonic or smallpox plagues.

B. Natural Selection: For the Birds

Adapted from Discovery Institute at the College of Staten Island (City University of New York), Exemplary Lesson #37. Used by permission of Dr. James Sanders, Director. (http://discovery.csi.cuny.edu/pdf/lesdonplandraft.pdf)

Teacher Preparation:

- Sunflower seeds or beans
- Five “beak” types (15 to 20 of each):
  Examples: Forceps, clothespins, plastic spoons, binder clips, hair clips, tongs, test tube holders, tongue depressors
- One plastic collection cup (16 ounce) per group
- Calculator or access to computer and http://www.lcusd.net/lchs/mewoldsen/APES/Unit04/blankBirdData.xls
- Class sets of each of the following: copies of lab, and graph paper or access to computers with spreadsheets
- Broom and dustpan

Natural Selection: For the Birds

Name: ______________________

Purpose

To simulate the natural selection of birds having different adaptations for feeding. Birds that eat enough will survive, reproduce, and pass on their advantageous beak type to the next generation.

Materials

Seeds, collection cup, and "beaks"

Procedure

1. Obtain beaks from the common area. Initially, there should be an approximately equal number of students in each "beak" group. Make sure to indicate types and number of beaks in table.
2. Locate group's collection cup.
3. Seeds will be spread over the common area by instructor.
4. Placing one hand behind their backs, everyone will have one minute to obtain seeds using only their "beaks" **from the common area** and place the seeds into their group's collection cup.
5. The seeds "eaten" by each "bird" will be counted, and a group total calculated and recorded in table.
6. The total "eaten" by the group will be reported to obtain a class total. This figure is needed to determine the number of beaks for the next generation (parents and offspring).
7. Calculate the number of birds earned for each group using this formula:

   Beaks for group in next generation = (Total seeds eaten by group) x Total # of birds in the population

Total seeds eaten

1. **NOTE**: The percentage of seeds eaten in the current generation is equal to the percentage of beaks in the next generation.
2. If your group ate relatively little food and thus earned fewer "birds" than you started with, some "birds" will die, must turn in their beaks, and become offspring for other groups. If your group ate a lot of food, it will earn more

"birds." These "birds" will be drawn from the group of extras and get a beak that is the same as the group they will be joining.

3. Steps 2 through 7 will be repeated three more times, thus accumulating four generations of data.
4. Graph percentage of beaks versus generation using five different lines representing the five different types of beaks (on graph paper or in spreadsheet).

Beak Type	Generation 1			Generation 2			Generation 3			Generation 4	
	Beaks		# of Seeds	Beaks		# of Seeds	Beaks		# of Seeds	Beaks	
	#	%		#	%		#	%		#	%
Total		100			100			100			100

Analysis

- How does genetic variation allow a population to survive during environmental changes?
- What type of food would be better for some of the nonsurviving birds?
- How does natural selection control the genetic diversity found in populations?
- Using your knowledge of natural selection, explain how extinction occurs.
- What would you predict would happen if in generation 5, a serving spoon beak was introduced?

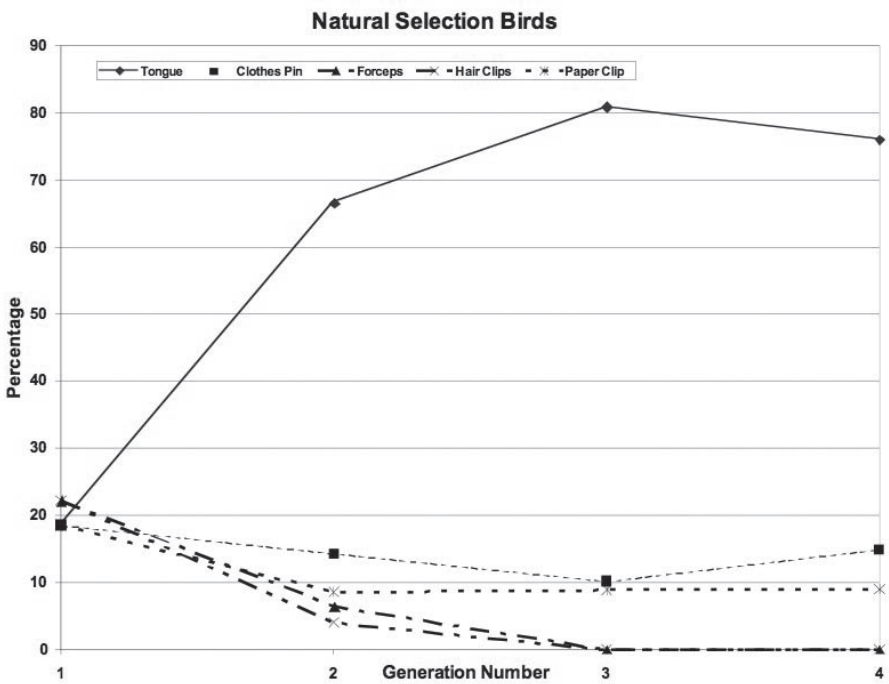
Conclusion

1. Summary of observations
2. How did you fulfill the purpose?

B. Natural Selection For the Birds: Teacher's Notes

Sample Data for Natural Selection For the Birds

Beak Type	Generation 1			Generation 2			Generation 3			Generation 4	
	Beaks		# of Seeds	Beaks		# of Seeds	Beaks		# of Seeds	Beaks	
	#	%		#	%		#	%		#	%
Tongue Depressor	5	19	2,872	18	67	3,259	22	81	3,561	21	76
Clothespin	5	19	618	4	14	420	3	10	699	4	15
Forcep	6	22	279	2	6	32	0	0	0	0	0
Hair Clip	6	22	175	1	4	18	0	0	0	0	0
Paper Clip	5	19	371	2	9	370	2	9	423	2	9
Total	**27**	**100**	**4,315**	**27**	**100**	**4,099**	**27**	**100**	**4,683**	**27**	**100**



Analysis

1. How does genetic variation allow a population to survive during environmental changes?

Genetic variation allows a population to survive during environmental changes by offering a greater variety of organisms. Even if a few of the organisms in a species cannot acclimate to the changed environmental conditions, it is likely that at least several of the organisms can acclimate *themselves to the changed environmental conditions. On the other hand, if there is little genetic variation, a single environmental change to which the entire species cannot adapt can cause the annihilation of the entire species.*

2. What type of food would be better for some of the nonsurviving birds?

   Small seeds would be better for some of the beaks, like the tweezers. However, larger seeds would work better for some of the other beaks, like the paper clip, since many of the small seeds slip through the paper clip. Larger seeds would ensure better grip and less likelihood for the seeds to slip through the beak.

3. How does natural selection control the genetic diversity found in populations?

   Natural selection controls the genetic diversity found in populations by eliminating those species or populations that are unable to obtain food, reproduce, etc. On the other hand, natural selection favors species/populations that are able to reproduce, find food, protect themselves, etc.

4. Using your knowledge of natural selection, explain how extinction occurs.

   Extinction occurs when species die. If a certain species has less desirable traits that are not ideal for the environment its members live in, then those of the species that are "stronger" will survive and those that are "weaker" will not live. A species becomes extinct by natural selection when particular traits no longer apply to its surroundings and another species takes over.

5. What would you predict would happen if in generation 5, a serving spoon beak was introduced?

   The balance of seeds between the various beaks would change, because the serving spoon beaks would likely take away much of the food supply away from the tongue depressors. The number of tongue depressor beaks and the number of serving spoon beaks would probably grow closer and closer.

Conclusion

1. *Summary of observations*

   The tongue depressor beaks were much more successful in obtaining food than were the hair clips. Eventually, the tongue depressors were able to get almost all the seeds, while the hair clips eventually died out. This means that, in a real ecosystem, the tongue depressor beaks would dominate over the hair clip beaks.

2. *How did you fulfill the purpose?*
   We fulfilled the purpose of the lab by finding out how genetic variation in a species will help determine the type of organisms that will survive in a certain ecosystem.

C. Adaptations for Plant Survival

- Information could be obtained individually or divided among table groups to fill in and then share.
- Information may be obtained online or at botanical gardens such as Huntington Gardens in San Marino, California.
- Under “biome,” indicate the general characteristics of the biome, while under “plant,” indicate the adaptations the plants have that allow them to survive under those conditions.
- This may be adapted for use with animals.

Plants		Light-influenced		Air-influenced		Water-influenced		Nutrient-influenced	
		Biome	Plant	Biome	Plant	Biome	Plant	Biome	Plant
Tropical	Rainforest								
	Savanna								
Temperate	Deciduous Forest								
	Coniferous Forest								
	Grassland								
Polar	Tundra								
	Taiga								
	Desert								

Partially Filled-In Chart

Plants		Light-influenced		Air-influenced		Water-influenced		Nutrient-influenced	
		Biome	Plant	Biome	Plant	Biome	Plant	Biome	Plant
Tropical	Rainforest	Varies greatly from canopies (lots) to ground (almost dark)	Huge leaves; Many shades of green; epiphytes huge leaves to allow time to reach emergent layer	Hot year round; emergent layer windy; calm other layers	Leaves huge; emergent layer shredded due to high winds	Lots of moisture	Tips of leaves drip water away very waxy leaves so do not soak in more water; roots shallow to allow contact with air	Low amount of nutrients in soil — all in plants	All nutrients in organisms; roots emerge to absorb decomposing organisms
	Savanna								
Temperate	Deciduous Forest								
	Coniferous Forest								
	Grassland								
Polar	Tundra								
	Taiga								
	Desert								

D. Organism Interactions

- Information could be obtained individually or divided among table groups to fill in and then share.
- Definition of each type of symbiotic relationship.
- Indicate the names of species below each relationship.
- If the relationship benefits the species, put it under the "+"
    - If the relationship harms the species, put it under the "–"
    - If the relationship has no affect on the species, put it under the "0"

	Competition		Commensalism		Mutualism		Parasitism		Predation	
Definition of Interaction										
	–	–	+	0	+	+	+	–	+	–
Desert — Tropic or Temperate										
Grassland— Tropic or Temprate										
Tropical Rainforest										
Deciduous Forest										
Boreal Forest										
Wetland										
Coral Reef										
Open Ocean										
Oligotrophic Lake										
Eutrophic Lake										
River — any part										

Partially Filled-In Chart

	Competition		Commensalism		Mutualism		Parasitism		Predation	
Definition of Interaction	The rivalry of two or more parties over something. Competition occurs naturally between living organisms that coexist in an environment with limited resources.		A term employed in ecology to describe a relationship between two living organisms where one benefits and the other is not significantly harmed or helped.		A biological interaction between individuals of two different species, where both individuals derive a fitness benefit; for example, increased survivorship.		A phenomenon in which two organisms which are phylogenetically unrelated coexist over a prolonged period of time, usually the lifetime of one of the individuals.		A biological interaction where a predator organism feeds on another living organism or organisms known as prey.	
	–	**–**	**+**	**0**	**+**	**+**	**+**	**–**	**+**	**–**
Desert - Tropic or Temperate	Rattlesnakes	Coral snakes	Burrowing owl	Cactus	Shrubs	Mycorr-hizae	Tape-worms	Humans	Armadillo lizard	Spiders
Grassland-Tropic or Temprate	Plants in the grassland compete for sunlight and nitrogen/ minerals available in the soil		Hyenas and vultures	lions	cattle egrets	cattle				
Tropical Rainforest										
Deciduous Forest										
Boreal Forest										
Wetland										
Coral Reef										
Open Ocean										
Oligotrophic Lake										
Eutrophic Lake										
River — any part										

E. Natural Selection: Owls and Mice

Name:__________________________________

Charles Darwin set sail on the *H.M.S. Beagle* (1831–6) to survey the South Seas (mainly South America and the Galapagos Islands) and to collect specimens of plants and animals. On the Galapagos Islands, Darwin observed species that lived nowhere else in the world. These observations led Darwin to write a book in 1859 titled *On the Origin of Species by Means of Natural Selection*. The two major ideas in the book was that species were not created in their present form but evolved from ancestral species, and that evolution takes a form that he called "natural selection."

The theory of natural selection indicates that inheritable variations exist in organisms and that due to environmental pressures, not all of the offspring of a species will survive. If a member of species survives, it has the opportunity to reproduce and its genes will be *selected* via its offspring for the next generation. On the other hand, if a member (or all members) of a species dies, its genes will not be *selected* to continue in the population.

Purpose

There are two purposes for this lab.

- To determine that natural selection is not a game of chance. Selection criteria choose against certain phenotypes, leaving them unable to produce offspring.
- To statistically show that the null hypothesis "Natural selection is completely random" is incorrect.

Materials

- 1 small cup (home tree)
- 50 paper chip "mice"—10 of 5 different colors
- Multicolored piece of cloth

Procedure

- Obtain multicolored cloth and spread on table. What are the major colors of the cloth? ____
- Get 50 paper chips from the stock containers.
- Ten of five different colors

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- Record the phenotypes (colors) in *Table 1* in columns A to E.
- Mix the chips in your cup and spread them evenly over the entire cloth.
- Imagine that the members of your table group are owls, the paper chips are mice, the paper cup is your home tree, and the fabric background is the habitat of the mice.
- You must locate and collect one mouse at a time (without licking fingers) and bring it back to your home tree.
- Collect a total of 40 mice as a table group, leaving 10 survivors.
- Separate and count the eaten mice and record in *Table 1*. Return the dead mice to the original stock containers.
- Carefully shake out the surviving mice to verify your results.
- Each of these mice is permanently pregnant and will give birth to four babies of its color.
- Go to the stock containers and collect the appropriate colored baby mice (total of 40 babies).
- Place the surviving mice and babies in cup.
- Repeat steps 3 to 7 two more times.
- Do a Chi-square analysis of your observed results in row T4.

TABLE 1

	Mice A	Mice B	Mice C	Mice D	Mice E	
Phenotype						Total
Total (T_1)	10	10	10	10	10	= 50
Dead (D_1)						= 40
Survivors ($S_1 = T_1–D_1$)						= 10
Babies ($B_1 = 4 \times S_1$)						= 40
T2 = $S_1 + B_1$						= 50
D_2						= 40
S_2						= 10
B_2						= 40
T_3						= 50
D_3						= 40
S_3						= 10
B_3						= 40
T_4						= 50

Chi-Square (χ^2) Analysis of Colored Mice

Science can never truly prove that a hypothesis is correct. Researchers can collect large amounts of evidence supporting the concept, but it only takes a single, valid experiment to disprove it. Scientists sometimes use the mathematical tool called statistics to help establish that an idea is statistically reliable. Statistics can also be used to show that an idea is statistically incorrect. A fairly simple statistical tool called Chi-Square (χ^2) analysis will be used.

The χ^2 obtained after plugging the numbers from row T_4 in **Table 1** into **Table 2** will be used to find the probability that the null hypothesis is correct. The probability obtained is dependent on the number of categories or number of colors of mice used in the experiment. Since there were five used, there are four degrees of freedom in the experiment. To find the probability, use your value in **Table 2** for χ^2= ___________. Look in the fourth row of **Table 3** to find the probability (*P*-value). For example, if your χ^2= 0.52, then the probability that the null hypothesis is correct is between .975 and .95, which means there is a 95 to 975 percent chance it is correct. If on the other hand your χ^2= 14.1, then the probability that the null hypothesis is correct is between .01 and .005, which means there is a 99 to 99.5 percent chance it is NOT correct.

TABLE 2

	Phenotype	Expected	Observed (T_4)	$\frac{(\text{Observed} - 10)^2}{10}$
A		10		
B		10		
C		10		
D		10		
E		10		+
			χ^2=	
			P =	

TABLE 3: CHI-SQUARE (X^2) PROBABILITIES

Degrees of Freedom	0.995	0.99	0.975	0.95	0.90	0.10	0.05	0.025	0.01	0.005
1	---	---	0.001	0.004	0.016	2.706	3.841	5.024	6.635	7.879
2	0.010	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210	10.597
3	0.072	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345	12.838
4	0.207	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277	14.860
5	0.412	0.554	0.831	1.145	1.610	9.236	11.070	12.833	15.086	16.750

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Analysis

- What were the hypotheses tested?
- How do your results differ from those of other table groups?
- What did the *P*-value indicate about the randomness of natural selection?

Conclusion

- Summarize your findings.
- How was the purpose fulfilled?

Sample Data for Natural Selection: Owls and Mice

TABLE 1

	Mice A	Mice B	Mice C	Mice D	Mice E	
Phenotype	Brown	Orange	Red	White	Yellow	Total
Total (T_1)	10	10	10	10	10	= 50
Dead (D_1)	5	8	7	10	10	= 40
Survivors ($S_1 = T_1 – D_1$)	5	2	3	0	0	= 10
Babies ($B_1 = 4 \times S_1$)	20	8	12	0	0	= 40
$T_2 = S_1 + B_1$	25	10	15	0	0	= 50
D_2	20	8	12	0	0	= 40
S_2	5	2	3	0	0	= 10
B_2	20	8	12	0	0	= 40
T_3	25	10	15	0	0	= 50
D_3	21	9	10	0	0	= 40
S_3	4	1	5	0	0	= 10
B_3	16	4	20	0	0	= 40
T_4	20	5	25	0	0	= 50

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TABLE 2

	Phenotype	Expected	Observed (T^4)	$\frac{(\text{Observed} - 10)^2}{10}$
A	Brown	10	20	10
B	Orange	10	5	1
C	Red	10	25	22.5
D	White	10	0	10
E	Yellow	10	0	+ 10
			χ^2=	52.5
			P =	.005<

Analysis

1. What were the hypotheses tested?

   We tested to see if the null theory that natural selection is completely random was incorrect. We also wanted to determine that natural selection is not a game of chance. Selection criteria choose against certain phenotypes, leaving them unable to produce offspring.

2. How do your results differ from those of other table groups?

   Our data differed from those of a lot of other tables.

3. What did the P-value indicate about the randomness of natural selection?

   The P-value indicated that natural selection is not *a random process but determined by other factors.*

Conclusion

1. Summarize your findings:

   Using the materials of confetti and a printed fabric, our lab group scattered these little bits of paper throughout our piece of cloth. Then we took away those confetti pieces that "stood out" in the dark, representing those species that are not able to camouflage effectively into their surroundings and thus die. After a few trials, only the black confetti pieces were left over.

2. How was the purpose fulfilled?

   In this lab, we tested the null hypothesis that states, "Natural selection is completely random." We hypothesized that if this were applied to a real-life situation, then the black ones would survive due to their camouflaging color. Thus, this proves that natural selection occurs, and the null hypothesis is not true.

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Community Interactions and Diversity

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Ecological Communities

Ecological communities, the collection of all living organisms within a given area in a given time, are an important concept in the AP Environmental Science course. Communities, like much of what is studied in this course, are dynamic rather than static. Organisms living within a community interact with each other. These interactions are defined as interspecific as they are *between* species rather than intraspecific, which would mean they are *within* species. Interspecific interactions or competition can involve a variety factors such as food, water, and habitat. However, it is important to note that when discussing interspecific competition, due to the definition of a species, it is not appropriate to discuss competition for mates.

Changes to a Community

Since communities are dynamic and changing over time, community succession can be measured. Succession is the change within a community following an environmental disturbance. The disturbance can be defined as natural (such as a volcano) or anthropogenic (such as a forest clear-cut). Succession is based on the fact that over time the biological community will recover from the disturbance. This recovery or succession tends to have a regular pattern determined by the disturbance and the community type.

There are two main categories of biological succession: primary and secondary. Primary succession is found in newly formed areas with little to no soil, such as volcanic islands. Secondary succession starts in areas that previously held life with fertile soil. Because of the length of time required to establish soil and soil fertility (thousands of years in some cases), an area undergoing secondary succession can recover from the disturbance much more rapidly than an area undergoing primary succession. Examples of typical primary successional areas are newly cooled volcanic rock, mudslides with complete loss of topsoil, and extreme fires that resulted in soil sterilization. Examples of typical secondary successional areas include a forest clear-cut, an abandoned farm field, and a vacant lot.

The first organisms to colonize an area undergoing succession are called the pioneer species. When discussing primary succession, these pioneer species are the nutrient and soil-building organisms such as bacteria, lichens, and mosses. When discussing secondary succession (where the soil is already present) the pioneer species are typically annual plant species that can grow, flower, and set seed rapidly under less-than-ideal conditions. After the pioneer species have colonized an area, the species composition continues to become more complex and to change through time from early successional species to midsuccessional species to late successional species. The final stage in succession is called the climax community. A climax community is the ultimate stage in succession and is the state in which the community composition is stable. The community would permanently contain this collection of species if no further disturbance occurred. The biodiversity of the climax community is determined primarily by the location (altitude and latitude) and the climate of that region. For example, the climax community of the Southwest's Sonoran Desert, which (in the driest regions) receives less than 75 mm of rain annually, is composed of xerophytic plants such as the leguminous palo verde tree, cholla cactus, and the saguaro cactus. The animals, like the Greater Roadrunner, desert tortoise, and the Banded Gila Monster, are also adapted to this dry climate.

Many ecologists reject the idea of a climax community since disturbance is a natural and inevitable part of all ecosystems. For them, the idea of a climax community is fleeting and false. These scientists point to the fact that communities are dynamic and ever-changing and have no endpoint. The rejection of a climax community is becoming more and more accepted among modern ecologists.

Successional stages move along a continuum, and there is not a clear delineation from one stage to the next. A community may have characteristics of more than one stage and, therefore, may be described as between two stages. An example of this would be describing an area as a mid- to late-successional state. In addition, a minimal disturbance may not completely decimate a community. As an example, a small fire may result in a community's moving from the late-successional stage to the midsuccessional stage. Also, when determining the successional stage of a species, it is helpful to think about the habitat and trophic level of the organisms. A bird that nests in old-growth forests is a later successional species than a smaller, bush-dwelling bird. A carnivorous spider cannot move into an area until a healthy population of prey or insects has been established in the region.

Since succession moves along this time continuum, species in earlier stages can impact the species in later successional stages. Scientists have described three typical patterns of interaction between earlier and later species. The first interaction, called facilitation, is when earlier successional species aid or help the species at a later stage. A lichen that chemically weathers rock (by secreting acid from the rootlets) is instrumental in soil formation. This soil formation obviously benefits plants residing in the region during later stages. The second interaction is called inhibition. In this type of interaction, an earlier successional species changes or degrades the environment in such a way that it hinders the growth of later species. The creosote bush is a common desert scrubland plant that exudes toxins from its roots to prevent other plant species from germinating in close proximity. This allelopathy (growth suppression of one plant species by a chemical secreted by another) hinders the growth of species not only in the same successional stage but also in later ones. This chemical impediment is a good example inhibition. The final interaction is called tolerance. In this model, earlier successional species do not have any appreciable impact on the later species. They neither hinder nor help their growth. Most biomes have all three of these interactions occurring at any given time.

Early successional species tend to be *r*-strategists with short lifespans, early reproductive age, large numbers of offspring, and low parental involvement. Examples of *r*-strategists are insects, rabbits, and deer. As a community continues to succeed, *K*-strategists migrate into the region. *K*-strategists, such as humans, elephants, and perennial plants, have longer lifespans, smaller numbers of offspring for each reproductive endeavor, later reproductive age, and large parental investment. A typical pattern of plant secondary succession is listed below with examples.

Plant Succession in a Typical Temperate Deciduous Forest

Successional Species	Early Successional	Mid-Successional	Late Successional	Climax*
Plant examples	Annual forbs (such as beebalm and Daucus sp.) Short-lived grasses (such as fallgrass or crabgrass)	Perennial grasses (such as poa sp.) Shrubs (such as sumac) Small trees (such as dogwood and cherry)	Pine trees (such as eastern white pine and loblolly pine)	Hardwood trees (such as white oak and shagbark hickory)

* Assumes the acceptance of the climax community theory.

Stability and Diversity Within a Community

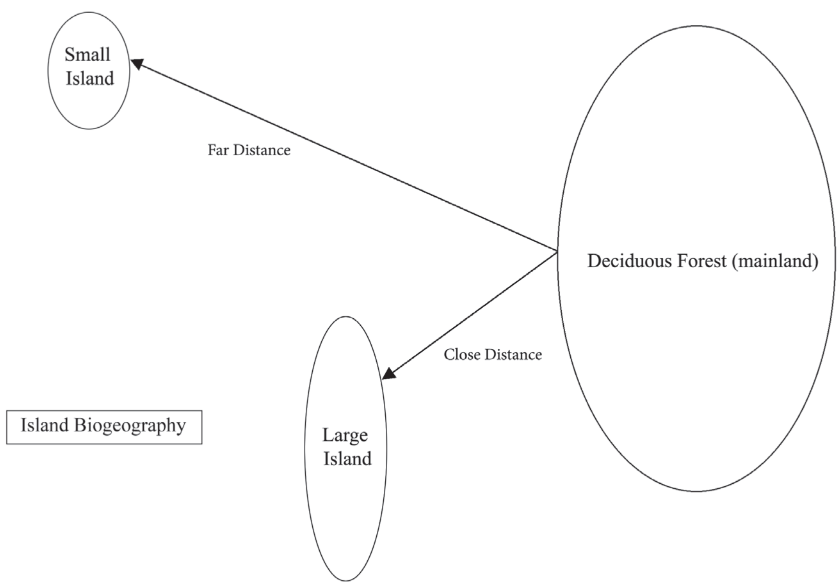
When discussing succession and disturbance, it is important to consider the stability of the community. Stability is defined by the overall health and diversity of a community. Ideally, a stable community is more able to resist and recover from a moderate disturbance. The disturbances described when discussing stability must be moderate because, realistically, no community can resist an extreme, devastating disturbance such as a group of humans with chainsaws. Ecological stability is defined by two main community characteristics. The first characteristic is resistance (sometimes also called persistence or inertia). Resistance is the ability of a community to resist change or a disturbance. If the disturbance is a wildfire, a mature boreal forest has high resistance while a grassland has low resistance. Most wildland wildfires tend to burn rapidly, frequently only scorching the trunks of the mature trees and burning the low-hour fuels (such as leaf litter, forest floor plants, and small saplings or trees). Typically the forest will suffer minimal permanent damage. A grassland community, on the other hand, which is composed mostly of quick-burning grasses and nonwoody plants, appears devastated by the wildland fire. This grassland has low resistance to a moderate disturbance such as the fire.

The second characteristic that defines a community's stability is resilience, which is the ability of a community to bounce back from a disturbance. Discussing the previously mentioned wildfire, the grassland has excellent resilience. Since the plants store most of their energy underground in bulbs and corms, this plant community rebounds very quickly from the fire. Within just a few days, one can spot new growth emerging from the ashes. The grassland, therefore, has high resilience. The boreal forest, on the other hand, could take years to recover if a wildfire swept through its canopy and killed mature trees. Trees take years to regrow, which results in low resilience for this ecosystem and community.

Analyzing both the resistance and the resilience of a community leads to a calculation of the area's stability. Some ecologists have stated that high biodiversity (combining high species evenness and high species richness) is required for a stable community. With an increase in biodiversity, all communities (whether forest or grassland) should be more resistant to disease or predation. This increased resistance lends itself to a more stable community. Other scientists remove biodiversity from the definition of stability. In addition, mathematical models are often used to define an area's stability.

The theory of island biogeography was developed by Robert MacArthur and E. O. Wilson in the 1960s. This theory makes predictions about the diversity found in communities. MacArthur and Wilson theorized that diversity is based on two factors: species immigration into a community and species loss (in the form of extinction) from a community. The combination of these two characteristics results in the diversity itself. Another aspect of the theory discusses islands and the species diversity found in these unique regions. An island, however, does not have to be land surrounded by water. An island can also be a natural habitat within a region of development. Central Park within the urban development of New York City is considered an island. When discussing islands and the species diversity on them, it is important to discuss two aspects. The first is the size of the island. A larger island has more "ecological space" so is able to hold more species. This is due to a combination of more possible niches (ecological roles), and less chance of extinction (due to larger populations and more communities). The second aspect is the distance of the island from the mainland (source of colonizing species). The closer the island is to the mainland, the greater the species' diversity. The most diverse community will have a large island close to the mainland, while the least diverse will have a small island far from the mainland. The figure below illustrates this theory.

FIGURE 1



Edge Effects

An edge effect occurs where one community or ecosystem ends and another begins. If the two ecosystems are still in a natural state, the resulting overlap is usually called an ecotone. An ecotone has abiotic factors that are different from the two receding ecosystems. The soil fertility and moisture values, sunlight levels, and other factors may differ wildly from the two stable ecosystems. The species found in an ecotone are usually a mixture of those found in the two ecosystems or, due to the varied climatic conditions, may be unique to the ecotone. As a result of the interaction, an ecotone tends to display greater biodiversity than the individual ecosystems.

An edge effect typically occurs when an ecosystem has been disturbed or fragmented in some capacity. If a portion of a tropical rainforest is burned, an edge effect will occur where the mature forest meets the newly cleared land. The disturbed portion will have an impact on the remaining forest. In this example, more sunlight will strike the forest floor, the soil moisture will decrease, and more wind can penetrate the remaining forest. These changes affect the organisms that live in the natural forest. This disturbance, and the resulting edge effect, can cause the loss of native species, the migration of native species, and the invasion of nonnative species. Edge effects undergo biological succession due to the disturbance involved.

Succession on Campus: An Observational Study

A high school campus, with the constant matriculation and graduation of students, is dynamic, or ever-changing. In this capacity, it resembles a natural system undergoing succession. Succession is the process by which the species composition and diversity of a natural area changes through time. In this activity, you will be researching an area on your campus that is in the process of succession. The plot that you are observing would ideally be large (at least 100 m^2), but this observation is still valid even if you attend an urban campus with minimal natural areas.

In this field activity, you will be observing both the plant and animal communities within your research area. The goal of this activity is to determine the successional stage of a natural area on your campus.

Procedure

1. Research Area Determination:
   In groups of three-to-four students, obtain your teacher's permission to find an area on campus that has been disturbed and is going through succession. Ideally, this research area should be as large as possible, but the study can still be conducted even if the plot is small (like a long-abandoned flower bed or former school garden). You should find an area as natural as possible; the unmowed baseball field is probably not a good choice.

2. Research Area Description:
   Before you begin walking through your plot (as this will bother the animals present), describe your research area on the data sheet (questions 1, 2, 3).

3. The Animal Community:
   In ecology, there are two ways to collect data. Researchers typically collect observational data or manipulation data. In this experiment, you will be collecting observational data on the animal community within your successional plot.

4. Direct Animal Observation:
   Sit quietly and spend 10 to 15 minutes observing your research area. If you and your group members are loud, many of the birds and small mammals could be scared away. While sitting quietly, fill in the Direct Animal Observation table on your data sheet. Do not worry if you do not know the names of the animals that you see. Use morphospecies (identification based on basic characteristics such as shape, size, and color) to fill in the data table. A sample is included on the data sheet.

   Make sure you look in trees and bushes for birds and small rodents. Quantify as many macroinvertebrates (insects, spiders, worms, isopods, etc.) as possible. Habitat (resting areas, nesting areas, food sources, etc.) is important for determining successional stage, so use your powers of observation.

5. Indirect Animal Observation:
   Even if the actual animals are not present, you can use the evidence of the animals to identify their presence in this research plot. Use the questions listed under the Indirect Animal Observation portion of the data sheet to help with this identification. Answer these questions now.

6. The Plant Community:
   Scientists frequently use research transects to identify plant species and composition. A transect is a research plot that cuts across or through your research area. Research transects can vary in size from tens of meters to kilometers long. For our study, the position of the transect must be randomly determined. This *randomness* can be achieved by using random GPS or compass coordinates or by something as simple as throwing a ball or walking random paces.

Ideally, your research transect should be at least 10 meters long (50 or 100 meters are better if your campus permits). Again, if your campus is fairly urban you may not have a transect that large. It is fine to have a transect that is smaller than 10 meters; just make sure you adjust your plant identification technique. Use a measuring tape or meter sticks with string to delineate your transect and read your transect regularly along the measuring tape. If your plot is 10 meters long, you may want to read a quadrat (a square of land that is analyzed for plants and animals) at 1-meter intervals. If your plot is 100 meters long, you may want to read a quadrat every 10 meters.

Choose one side of the measuring tape or string (either right or left, and be consistent) and use meter sticks to outline a meter square quadrat or research plot. You will read all the plants that fall within this meter.

Reading consists of one group member identifying *all* species within *each* quadrat. In order to determine succession, it is most important to figure out plant form (such as annual, perennial herb, shrub, small tree, or large tree) rather than individual species. Similarly to our animal data, use morphospecies if you do not know the true name of the plant species. When looking at the quadrat, if it is impossible to identify the number of plants (this is important for our perennial plants such as grasses or creeping plants), then focus on percent cover (for example, 10 percent of the ground is covered by this plant; 25 percent, etc.). Record your data on the data sheet. Please note that you may have three or four species within one meter (see sample). While making your observations, consider the following questions:

a. What is the form of the plant? Is it:
   - annual (grows, flowers, and sets seed all in one year);
   - perennial (a plant that lives more than one year, such as a grass);
   - a shrub (a small, woody plant, such as a lilac);
   - a small tree (such as a cherry); or
   - a large tree (such as an oak tree or a beech tree)?

b. Is the plant flowering?

c. Are seed pods present on the plant? Are they dried or fresh?

7. Clean-Up:

   When you have finished collecting your data, collect your research tools (meter sticks, measuring tapes, string), and return to the classroom. Answer the questions individually at home. Some require outside research.

Analysis Questions

Answer these questions on a separate sheet of paper. Each question should contain complete, analytical answers in complete sentences.

1. Is your plot undergoing primary or secondary succession? Explain in complete sentences. A complete answer will use the data that you collected in questions 1, 2, and 3.
2. Using the field data that you collected, determine the successional stage of your plot. Which of the following is it?

   a. early
   b. mid
   c. late
   d. climax

   A complete answer will include an analysis of both your plant and animal data in your final stage determination. Please use your data in your description. Remember: Succession moves along a continuum, which means that your plot may not fall neatly into one of the categories above. It is perfectly acceptable to determine your stage as a mixture of two stages, such as mid–late successional.
3. Some ecologists do not subscribe to the theory of a climax community. What is a climax community? Why do some ecologists believe they do not exist?
4. Doing outside research, what would the final successional stage of your campus be? If your school was removed and allowed to go through succession, what native plants and animals would you find? How long do you think it would take your campus to reach the climax community?

Succession on Campus: An Observational Study—Teacher's Guide

A high school campus, with the constant matriculation and graduation of students, is dynamic, or ever-changing. In this capacity, it resembles a natural system undergoing succession. Succession is the process by which the composition of a species and diversity of a natural area changes through time. In this activity, you will be researching an area on your campus that is in the process of succession. The plot that you are observing would ideally be large (at least 100 m^2), but this observation is still valid even if you attend an urban campus with minimal natural areas.

In this field activity, you will be observing both the plant and animal communities within your research area. The goal of this activity is to determine the successional stage of a natural area on your campus.

Procedure

1. Research Area Determination:
   In groups of three-to-four students, obtain your teacher's permission to find an area on campus that has been disturbed and is going through succession. Ideally, this research area should be as large as possible, but the study can still be conducted even if the plot is small (like a long-abandoned flower bed or former school garden). You should find an area as natural as possible; the unmowed baseball field is probably not a good choice.

   Depending on the size of your campus, students may or may not be able to find a large natural area. Students should still do the observation even if they can only find a very small, narrow strip of land. The results should still be significant. It is important, however, that the students focus on an area that has not been recently gardened. Possible research locations on campus include untouched strips of land behind gardened areas, regions adjacent to the campus periphery, and long-abandoned school gardens.

2. Research Area Description:
   Before you begin walking through your plot (as this will bother the animals present), describe your research area on the data sheet (questions 1, 2, 3). Students should describe their plot and include an estimate of size. This exercise is a good opportunity to teach the students estimation techniques.

3. The Animal Community:
   In ecology, there are two ways to collect data. Researchers typically collect observational data or manipulation data. In this experiment, you will be collecting observational data on the animal community within your successional plot.

4. Direct Animal Observation:
   Sit quietly and spend 10 to 15 minutes observing your research area. If you and your group members are loud, many of the birds and small mammals

could be scared away. While sitting quietly, fill in the Direct Animal Observation table on your data sheet. Do not worry if you do not know the names of the animals that you see. Use morphospecies (identification based on basic characteristics such as shape, size, and color) to fill in the data table. A sample is included on the data sheet. Depending on the identification skills of your students, most of their data may be in the form of morphospecies.

Make sure you visually look in trees and bushes for birds and small rodents. Quantify as many macroinvertebrates (insects, spiders, worms, isopods, etc.) as possible. Habitat is important for determining successional stage, so use your powers of observation (resting areas, nesting areas, food sources, etc.).

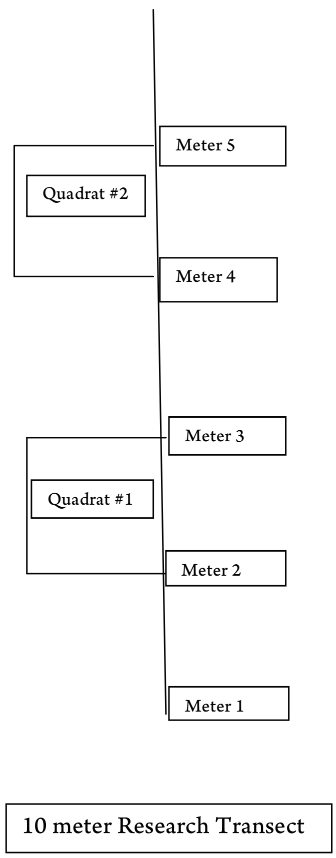
5. Indirect Animal Observation:
   Even if the actual animals are not present, you can use the evidence of the animals to identify their presence in this research plot. Use the questions listed under the Indirect Animal Observation portion of the data sheet to help with this identification. Answer these questions now. There may be additional observation data that students may find. Students often find animal tracks, spiderwebs, animal holes, copious bird feathers, or empty nests.

6. The Plant Community:
   Scientists use research transects to identify plant species and composition. A transect is a research plot that cuts across or through your research area. Research transects can vary in size from tens of meters to kilometers long. In order to be valid, the position of the transect must be randomly determined. This can be achieved by using random GPS or compass coordinates or by something as simple as throwing a ball or walking random paces. Students should randomly select the location and direction of their plot. This can be accomplished using one of the techniques listed above. To determine the random GPS or compass coordinates, a student can shut her or his eyes and punch random numbers into a calculator. That resulting number is the coordinate of the start of the research plot.

   Ideally, your research transect should be at least 10 meters long (50 or 100 meters are better if your campus permits). Your students should still get results even if their plot is much smaller than 10 meters. Again, if your campus is fairly urban, you may not have a transect that large. It is fine to have a transect that is smaller than 10 meters; just make sure you adjust your plant identification technique. Use a measuring tape or meter sticks with string to delineate your transect and read your transect regularly along the measuring tape. If your plot is 10 meters long, you may want to read a quadrat (a square of land that is analyzed for plants and animals) at 1-meter intervals. If your plot is 100 long, you may want to read a quadrat every 10 meters.

Choose one side of the measuring tape or string (either right or left, and be consistent) and use meter sticks to outline a meter square quadrat or research plot. You will read all the plants that fall within this meter. It may help to draw a picture of this on the board before students go to their field sites. A sample drawing is found below.

FIGURE 2



Reading consists of one group member identifying *all* species within *each* quadrat. In order to determine succession, it is most important to figure out plant form (such as annual, perennial herb, shrub, small tree, large tree) rather than individual species. Similarly to our animal data, use morphospecies if you do not know the true name of the plant species.

When looking at the quadrat, if it is impossible to identify the number of plants (this is important for our perennial plants such as grasses or creeping plants), then focus on percent cover (for example, 10 percent of the ground is covered by this plant; 25 percent, etc.). Percent cover refers to the percentage of the quadrat that is covered by that plant. This information can be determined by standing up, looking down on the entire quadrat, and estimating coverage. Record your data on the data sheet. Please note that you may have three or four species within one meter (see sample). While making your observations, consider the following questions:

a. What is the form of the plant? Is it:
   - annual (grows, flowers, and sets seed all in one year);
   - perennial (a plant that lives more than one year, such as a grass);
   - a shrub (a small, woody plant, such as a lilac);
   - a small tree (such as a cherry);
   - a large tree (such as an oak tree or a beech tree)?

b. Is the plant flowering? This is helpful for morphospecies identification.

c. Are seedpods present on the plant? Are they dried or fresh? This will help the students determine if the plant is an annual or perennial. If old seeds are present, it should indicate that the plant is a perennial.

7. Clean-Up:
   When you have finished collecting your data, collect your research tools (meter sticks, measuring tapes, string) and return to the classroom. Answer the questions individually at home. Some require outside research.

Analysis Questions

Answer these questions on a separate sheet of paper. Each question should contain complete, analytical answers in complete sentences.

1. Is your plot undergoing primary or secondary succession? Explain in complete sentences. A complete answer will use the data that you collected in questions 1, 2, and 3.

   Our plot is an abandoned area behind our softball batting cages. According to the facilities department at our school, this area has not been mowed or developed for at least five years. This plot is about 100 meters by 75 meters.

Soil is present in this area and, therefore, the region is undergoing secondary succession.

2. Using the field data that you collected, determine the successional stage of your plot. Is it:
   a. early
   b. mid
   c. late
   d. climax

   A complete answer will include an analysis of both your plant and animal data in your final stage determination. Please use your data in your description. Remember: Succession moves along a continuum, which means that your plot may not fall neatly into one of the categories above. It is perfectly acceptable to determine your stage as a mixture of two stages such as early–mid or mid–late successional.

Based on the data, this research plot is in mid–late succession. This conclusion was made because of the nine plant species identified, three of them were woody (lilac shrub, dogwood tree, and pine tree). The nonwoody species were mostly perennials, meaning that they live more than one year. Perennial species such as the two grasses (grass 1 and grass 2), Achillea, and the vine are most commonly found in later successional regions. If a large amount of weeds or annuals were found, the plot may have been identified as earlier in the successional time frame.

The animal data mostly supports this mid–late successional age estimation. Most of the species found in the research plot are macroinvertebrates such as the three butterflies, two spiders (plus four abandoned webs), and ants. There was only one species of small mammal (mice) actually spotted, but indirect evidence indicated that a small carnivore (perhaps a fox) and other small mammals such as rabbits live in the area. Some songbirds were found in the plot, and according to our principal, an owl has been spotted in this part of campus. In a later successional research area, one would expect to find larger herbivores such as deer and bison. Since the research area is found in close proximity to humans, it is not surprising that these species are absent.

3. Some ecologists do not subscribe to the theory of a climax community. What is a climax community? Why do some ecologists believe they do not exist?

   A climax community is the last stage of succession. Some ecologists do not believe that climax communities exist because communities are fluid and dynamic and ever-changing. Because disturbance is inevitable, a climax community will never occur.

4. Doing outside research, what would the final successional stage of your campus be? If your school was removed and allowed to go through succession, what native plants and animals would you find? How long do you think it would take your campus to reach the climax community?

   Our campus is located in Central Illinois. If the campus buildings were removed and the area began succession, it would eventually return to a productive grassland. A variety of grasses and forbs would grow in the fertile soil. Some specific plant species are big bluestem (grass), little bluestem (grass), rye (grass), purple coneflower (forb), compass plant (forb), and butterfly weed (forb). Large trees would be restricted by the regular fires that are started by lightning. The fires are currently suppressed to prevent building damage. Animals such as prairie chickens, monarch butterflies, bison, and even wolves would eventually return to the area. The area would reach its climax community in about 25 to 50 years.

Succession on Campus: An Observational Study (APES) Data Sheet

Name: ________________________ **Period:** ____________

1. Description of Research Area (include approximate size and location):
2. Is there evidence as to the original cause of this disturbance? Describe in complete sentences below.
3. Is soil present in this area?
4. Direct Animal Observation

Direct Animal Data Table

Animal Species/ Morphospecies Description	Number of Individuals	Habitat	Observations
SAMPLE: Small brown bird	3	Tree-dwelling	Eating a worm (carnivorous)

5. Indirect Animal Observation:
   a. Mammal/Reptile Activity: Are animal tracks visible? Is scat (animal feces) present in your plot? Are there any obvious holes where animals are hiding? Describe below.
   b. Bird Activity: Are there any bird tracks or feathers? Do you see any presence of nests? Do the birds live in trees (like robins) or on the ground (like California quail)? Can you determine whether they are seed eaters, berry eaters, macroinvertebrate feeders, or birds of prey? Describe below.
   c. Insect Activity: Is there evidence of insect activity such as webs or molted exoskeletons? Describe below.
6. Plant Community Data: Length of Transect:____________________

Plant Data Table

Meter Mark	Plant Species/ Morphospecies	Number of Individuals	Plant Form*	Additional Observations**
SAMPLE Meter 1	Acer rubrum (Red Maple)	1	Large tree	This tree covered 50 per cent of the meter 1 quadrat.
SAMPLE Meter 1	Small little plant with red flowers	3	Perennial	These plants still had last year's seedpods on them. Therefore, they are perennial plants.

* Annual, perennial, shrub, small tree, or large tree

** Some questions to consider: Is the plant flowering? Are seedpods present? How large is the plant? Is the plant woody or herbaceous?

Succession on Campus: An Observational Study (APES) Data Sheet

Name: ______________________ SAMPLE _____________ Period: _________

1. Description of Research Area (include approximate size and location):
   We researched the area behind the softball batting cages. This area is about 100 m by 75 m.
2. Is there evidence as to the original cause of this disturbance? Describe in complete sentences below.
   We think that the area was mowed and the original vegetation was removed to build the softball batting cages.
3. Is soil present in this area?
   Yes, soil is present in this area.
4. Direct Animal Observation

Direct Animal Data Table

Animal Species/ Morphospecies Description	Number of Individuals	Habitat	Observations
SAMPLE: Small brown bird	3	Tree-dwelling	Eating a worm (carnivorous).
Honeybee hive	About 400	Hive found in tree	Bees were swarming.
Spider in a web	2	Web on a small tree	Two flies were found in the web.
Male and female goldfinches	2	Tree	The finches were nesting in a small tree.
Ants	About 100	Nest in the ground	A small nest was found on the ground.
Blue butterflies	3	Flying in air	
Mice	4	Scurrying up small tree	Mice were eating seeds from tree.
Lizards	4	Hole in ground	Lizards were crawling out of hole in ground.

5. Indirect Animal Observation:
   a. Mammal/Reptile Activity: Are animal tracks visible? Is scat (animal feces) present in your plot? Are there any obvious holes where animals are hiding? Describe below.
   We found small mammal tracks throughout the research area. We think that these belong to a small carnivore like a fox. We also found a small pile of round scat. We think the scat was deposited by a rabbit.

b. Bird Activity: Are there any bird tracks or feathers? Do you see any presence of nests? Do the birds live in trees (like robins) or on the ground (like California quail)? Can you determine whether they are seed eaters, berry eaters, macroinvertebrate feeders, or birds of prey? Describe below.

The principal has said that an owl has been seen in this area of campus. Owls are birds of prey.

c. Insect Activity: Is there evidence of insect activity such as webs or molted exoskeletons? Describe below.

We found four abandoned spiderwebs. Since all four webs had different shapes, we assume that they were made by four different spiders.

6. Plant Community Data: Length of Transect: _________ 25 meters__________

Plant Data Table

Meter Mark	Plant Species/ Morphospecies	Number of Individuals	Plant Form*	Additional Observations**
SAMPLE Meter 1	Acer rubrum (Red Maple)	1	Large tree	This tree covered 50% of the meter 1 quadrat.
SAMPLE Meter 1	Small little plant with red flowers	3	Perennial	These plants still had last year's seedpods on them. Therefore, they are perennial plants.
Meter 1	Small vine	15% cover	Perennial	
Meter 1	Pine tree	1	Small tree (sapling)	This is a very small tree. It is less than 1 meter tall.
Meter 5	Dogwood Tree	1	Small tree	Tree is about 3 meters tall and has a finch nest in it.
Meter 5	Medium purple flower	4	Annual?	Plant looks weedy, but I am not sure if it is a perennial or annual.
Meter 5	Small vine	1	Perennial	Vine has started winding around the dogwood.
Meter 10	Small grass bunch (grass #1)	5% cover	perennial	Most of this plot was bare ground.
Meter 15	Lilac shrub	1	Medium shrub	
Meter 15	Grass (grass #1)	40% cover	Perennial	This is the same grass found in meter 10.
Meter 20	Achillea	2	Perennial	These plants still had last year's seeds on it.
Meter 20	Grass (grass #2)	3 bunches	Perennial	This is the second grass found in this transect. It is flowering.
Meter 20	Pine tree	1	Small tree (sapling)	This is another very small tree.
Meter 25	Achillea	3	Perennial	
Meter 25	Grass (grass #2)	40% cover	Perennial	

* Annual, perennial, shrub, small tree, or large tree

** Some questions to consider: Is the plant flowering? Are seedpods present? How large is the plant? Is the plant woody or herbaceous?

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Ecological Calculations

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One of the four free-response questions on the AP Environmental Science Exam is a data set question. Students are required to perform mathematical calculations in order to obtain answers to some parts of these questions. Often, students skip this portion of the question, do not show their work, or have difficulty using scientific notation. Additionally, students have demonstrated that they are not familiar with the metric system and/or common metric prefixes. These sets of ecological calculations focus on these areas. Sets one, two, and three are meant to be done without using a calculator; set four, calculating biodiversity indices, is designed to increase the student's ability in using a spreadsheet to help analyze data.

Ecological Footprint

In our quest to attain a sustainable planet, a question that is often asked is, "How many people can the planet support?" It can be argued that the earth has already reached its carrying capacity. Evidence to support that conclusion would include increasing degradation of the planet's air and water quality along with a decrease in arable land. Population size, affluence, and technology are contributing factors to the human population's impact on the planet (Miller 2008). However, environmental impacts are not created equally; the developing countries represent about 82 percent of the world's population, yet they consume only about 25 percent of the world's resources. The United States, at about 4.6 percent of the world's population, consumes about 25 percent of the world's resources.

The idea of a human ecological footprint was first proposed by Wackernagel and Rees in 1996. The definition they proposed for an ecological footprint is "the amount of productive land and water surface to support all the needs of a person." In the United

States the average size of an American's footprint is 9.7 hectares, while in India the average value is 0.8 hectares. Although this assignment utilizes averages values for ecological footprints, students can visit many different Web sites to calculate their ecological footprint. This exercise will help students understand the magnitude of the U.S. footprint, and it will allow them to predict the impact on the planet if the majority of the world had a similar footprint.

Ecological Footprint Activity — Student Sheet

Land area of the planet = 150 million km^2

Water Area = 361.8 million km^2

Country	Population (thousands)	Ecological Footprint (hectares/person)	Ecological Footprint (km^2/person)
United States	301,140	9.7	
Canada	33,390	8.8	
China	1,322,000	1.6	
Japan	127,433	4.8	
Indonesia	234,694	1.1	
India	1,130,000	0.8	
Pakistan	164,742	0.6	

* Population data was obtained from www.census.gov

1. Complete the table by converting hectares per person into km^2 per person.
2. Calculate the total area required by each country.
3. Calculate the percentage of the planet needed to sustain each country's population.
4. If China and India had the same footprint as the United States, would the earth be able to sustain its population? How much of the planet would it take to support those countries?
5. The current population (mid-2007) of the world is about 6.7 billion people. At its current rate of growth, the population should reach 13.4 billion people in about 60 years. If everyone on the planet has an ecological footprint equivalent to that of the United States, how many earths will be required to support the population at that rate of consumption?

Ecological Footprint Activity – Answer Sheet

Country	Population (in 000's)*	Ecological Footprint (hectares/ person)	Ecological Footprint (km^2/ person)	Total Area per Country (km^2)	% of the Earth's Land Area	% of the Earth's Ocean Area	% of the Earth's Total Surface Area
United States	301,140	9.7	0.097	29,210,580	19.47%	8.09%	5.72%
Canada	33,390	8.8	0.088	2,938,320	1.96%	0.81%	0.57%
China	1,322,000	1.6	0.016	21,152,000	14.10%	5.86%	4.14%
Japan	127,433	4.8	0.048	6,116,784	4.08%	1.69%	1.20%
Indonesia	234,694	1.1	0.011	2,581,634	1.72%	0.71%	0.51%
India	1,130,000	0.8	0.008	9,040,000	6.03%	2.50%	1.77%
Pakistan	164,742	0.6	0.006	988,452	0.66%	0.27%	0.19%
			Sample Calculation	**Ecological Footprint (km^2/person)**			
hectare = 10,000 m^2			9.7 hectares/person *301,140,000 persons* 10,000 m^2/hectare * 1 km^2 / 1,000,000m^2				
1 km2 = 1,000,000m^2							
150,000,000	Earth's land area						
361,100,000	Earth's ocean area						
511,100,000	Earth's total area (km^2)						
4.China			**5. Entire Planet**				
128,234,000	Total area (km^2)		1,299,800,000	Total area (km^2)			
85.49%	% land area		254.31%	% total surface			
35.51%	% ocean area		At the world's current population, it would take 2.54 earths to support a world with the same ecological footprint as the population of the United States.				
25.09%	% total surface						
India							
109,610,000	Total area (km^2)						
73.07%	% land area						
30.35%	% ocean area						
21.45%	% total surface						
China + India + U. S. =	178.04%	Land area					
	73.96%	Ocean area					
	52.25%	Total Area					

Net Primary Productivity in Ecosystems

Gross primary productivity (GPP) can be described as the rate at which plants convert solar energy into chemical energy (organic compounds). Net primary productivity is the organic compounds left over for consumers. NPP = GPP – R. R represents the energy that is used in carrying out respiration. Various ecosystems have different NPP.

In this exercise, students will compare the NPP of different ecosystems and rank those ecosystems based on their average global NPP.

Net Primary Productivity Activity — Student Sheet

Complete the following table by calculating the global NPP for each of the ecosystems listed. Calculators may not be used for this assignment. Please show all your work, including units. Display all answers using scientific notation. Arrange the ecosystems from least productive to most productive based on global NPP and then by NPP. Are these tables identical? If not, please explain why.

TABLE 1: NET PRIMARY PRODUCTION OF SELECTED ECOSYSTEMS

Ecosystem	Area (million km^2)	Mean NPP per unit area ($g/m^2/yr$)	Global NPP (billion metric tons/yr)	Global NPP (metric tons/yr)
Algal beds and reefs	0.6	2,500		
Boreal forest	12.0	800		
Continental shelf	26.6	360		
Cultivated land	14.0	650		
Desert shrub	18.0	90		
Estuaries	1.4	1,500		
Extreme desert, rock, sand, and ice	24.0	3		
Lake and stream	2.0	250		
Open ocean	332.0	125		
Savannah	15.0	900		
Swamp and marsh	2.0	2,000		
Temperate deciduous forest	7.0	1,200		
Temperate evergreen forest	5.0	1,300		
Temperate grassland	9.0	600		
Tropical rainforest	17.0	2,200		
Tundra and alpine meadow	8.0	140		

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Net Primary Productivity Activity — Answer Sheet

Complete the following table by calculating the global NPP for each of the ecosystems listed. Calculators may not be used for this assignment. Please show all your work, including units. Display all answers using scientific notation. Arrange the ecosytems from least productive to most productive based on global NPP and then by NPP. Are these tables identical? If not, please explain why.

TABLE 1: NET PRIMARY PRODUCTION OF SELECTED ECOSYTEMS (BASED ON GLOBAL PRODUCTION)

Ecosystem	Area (million km^2)	Mean NPP per unit area ($g/m^2/yr$)	Global NPP (billion metric tons/yr)	Global NPP (metric tons/yr)
Extreme desert, rock, sand, and ice	24.0	3	0.07	7.0×10^{7}
Lake and stream	2.0	250	0.5	5.0×10^{8}
Tundra	8.0	140	1.1	1.1×10^{9}
Algal beds and reefs	0.6	2,500	1.5	1.5×10^{9}
Desert and semidesert scrub	18.0	90	1.6	1.6×10^{9}
Estuaries	1.4	1,500	2.1	2.1×10^{9}
Swamp and marsh	2.0	2,000	4.0	4.0×10^{9}
Temperate grassland	9.0	600	5.4	5.4×10^{9}
Temperate evergreen forest	5.0	1,300	6.5	6.5×10^{9}
Temperate deciduous forest	7.0	1,200	8.4	8.4×10^{9}
Cultivated land	14.0	650	9.1	9.1×10^{9}
Continental shelf	26.6	360	9.6	9.6×10^{9}
Boreal forest	12.0	800	9.6	9.6×10^{9}
Savannah	15.0	900	13.5	1.35×10^{10}
Tropical rain forest	17.0	2,200	37.4	3.74×10^{10}
Open ocean	332.0	125	41.5	4.15×10^{10}

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TABLE 2: NET PRIMARY PRODUCTION OF SELECTED ECOSYSTEMS (BASED ON MEAN NPP)

Ecosystem	Area (million km²)	Mean NPP per unit area (g/m²/yr)	Global NPP (billion metric tons/yr)	Global NPP (metric tons/yr)
Extreme desert, rock, sand, and ice	24.0	3	0.07	7.0×10^{7}
Desert and semidesert scrub	18.0	90	1.6	1.6×10^{9}
Open ocean	332.0	125	41.5	4.15×10^{10}
Tundra	8.0	140	1.1	1.1×10^{9}
Lake and stream	2.0	250	0.5	5.0×10^{8}
Continental shelf	26.6	360	9.6	9.6×10^{9}
Temperate grassland	9.0	600	5.4	5.4×10^{9}
Cultivated land	14.0	650	9.1	9.1×10^{9}
Boreal forest	12.0	800	9.6	9.6×10^{9}
Savannah	15.0	900	13.5	1.35×10^{10}
Temperate deciduous forest	7.0	1,200	8.4	8.4×10^{9}
Temperate evergreen forest	5.0	1,300	6.5	6.5×10^{9}
Estuaries	1.4	1,500	2.1	2.1×10^{9}
Swamp and marsh	2.0	2,000	4.0	4.0×10^{9}
Tropical rainforest	17.0	2,200	37.4	3.74×10^{10}
Algal beds and reefs	0.6	2,500	1.5	1.5×10^{9}

The differences are based on the areas of the given ecosystems.
Data from Chiras 1994, 41; Smith 1998, 319.

Energy Flow through Ecosystems/Pyramids of Energy/ Biomagnification

Questions

Methods of investigating energy flow through an ecosystem include examining a pyramid of numbers, of energy, or of biomass. Due to respiration and the second law of thermodynamics, 100 percent of the energy is never passed from one trophic level to the next. The amount of usable energy passed, as biomass, from one level to the next is dependent on the efficiency of the organisms. The idea of trophic levels and energy flow through those levels was first proposed by Lindemann in 1942. The average ecological efficiency between trophic levels is about 10 percent, but it can vary from 2 percent to 40 percent, while plants have a photosynthetic efficiency of 1 to 3 percent.

In this activity, students will calculate the amount of energy passed from one trophic level to the next based on the ecological efficiencies of the organisms. Additionally, students will examine the concept of biomagnification.

The information in the following table represents the energy flow in a hypothetical spring in Florida. Unfortunately, the spring experienced a DDT spill. The concentration of DDT found in the organisms at each trophic level is also given in the table below.

TABLE 1: ENERGY FLOW AND DDT CONCENTRATIONS FOR THE OKEECHOBEE SPRING IN OKEECHOBEE, FLORIDA

Trophic level	Productivity (kcal/m^2/yr)	DDT Present (ppm)([1])
Producers	9,000	0.04
Primary Consumers (herbivores)	1,500	0.23
Secondary Consumers (carnivores)	120	2.07
Tertiary Consumers (top carnivores)	12	13.8

1. Calculate the efficiency of energy transfer from:
   a) Producers to primary consumers
   b) Primary consumers to secondary consumers
   c) Secondary consumers to tertiary consumers
2. What percent of the energy from the producers is transferred to the tertiary consumers?
3. The concentration of DDT in the water was 1.0 X 10^{-8} mg/L.
   a) How many times more concentrated is the DDT in the producers as compared to the water?
   b) Calculate the ratios of DDT between trophic levels, as it accumulates from producers to primary consumers, primary consumers to secondary consumers, and secondary consumers to tertiary consumers.

Answers

TABLE 1: ENERGY FLOW AND DDT CONCENTRATIONS FOR THE OKEECHOBEE SPRING IN OKEECHOBEE, FLORIDA

Trophic level	Energy Available (kcal/m²/yr)	Ecological Efficiency	DDT Present (ppm)(1)	Increases in DDT
Producers	9,000		0.04	
Primary Consumers (herbivores)	1,500	16.67%	0.23	5.75
Secondary Consumers (carnivores)	120	8.00%	2.07	9.00
Tertiary Consumers (top carnivores)	12	10.00%	13.8	6.67
Per cent of energy from producers to tertiary consumers 0.13% Increase from producers to tertiary consumers 345.00				

Work

1. a) (1500/9000) * 100 = 16.7%	2. (12/9000) * 100 = 0.13%	3. a) $(4 \times 10^{-2} / 1 \times 10^{-8}) = 4 \times 10^{6}$
b) (120/1500) * 100 = 8.0%		b) i) (0.23 / 0.4) = 5.75
c) (12/120) * 100 = 10.0%		ii) (2.07 / 0.23) = 9.0
		iii) (13.8 / 2.07) = 6.67

Species Diversity Calculations/Population Density

Although the term "biodiversity" is relatively new (coined by E. O. Wilson in 1980), species diversity indices have been calculated for more than 150 years. Species diversity plays an important role in a community's structure. Along with diversity, species richness (the number of different species) and species evenness (number of individuals within a given a given species) can also be evaluated. The Shannon–Wiener index takes into account both the number of species and species evenness in calculating this index. Values range from 0 to about 4.5. Higher values may indicate a more diverse community.

The data below were collected at the Center for Environmental Education, Key Biscayne, Florida, by students between 2002 and 2005. Students can compare the data sets and see if there have been any significant changes in those communities during that time span. All data were collected at low tide at approximately the same location. Students can calculate these values using a calculator, but these data can also be analyzed using an Excel spreadsheet.

Using the data in the following tables, calculate the Shannon–Wiener Diversity Index, species richness value, and population density for the organisms in these sea grass communities. All data were collected at approximately the same location on Key Biscayne between 10 and 11 a.m. The tables contain data collected between 2002 and 2005.

Data Sheet

Data Sheet for Shannon–Wiener Diversity Index

Transect = 10m X 10m

Catch Data from the Center For Environmental Education, Key Biscayne, FL				Shannon–Weiner Diversity Index		
7/29/2002	**Water Temperature = 28 degrees C**			**$H = -\Sigma p_i * \ln p_i$**		
Phylum	**Common Name**	**Quantity(ni)**	**n_i**	**p_i**	**$\ln p_i$**	**$p_i * \ln p_i$**
Porifera	Heavenly/blue sponge	2	2			
	Chicken liver sponge	1	1			
	Red sponge	2	2			
Mollusca (Univalves)	Cerith	13	13			
	Marginella	1	1			
	Turban	13	13			
	Drill	1	1			
Arthropoda (shrimp)	Cleaning shrimp	1	1			
	Edible/pink shrimp	1	1			
	Mantis shrimp	3	3			
Arthropoda (crabs)	Blue/swimming crab	6	6			
	Hermit crab	1	1			
	Spider/decorator crab	3	3			
Arthropoda (other)	Florida lobster	1	1			
Chordata	Goby	6	6			
	Grunt	1	1			
	Parrot	2	2			
	Pipe	15	15			
	Scorpion	1	1			
	Snapper	3	3			
	Toad	3	3			
	Trunk (juv. - "pea fish")	5	5			
	TOTAL	85				
Species Richness =					**H =**	
Species Evenness = H/ln R						
Population Density =						

Catch Data from the Center For Environmental Education, Key Biscayne, FL				Shannon–Weiner Diversity Index		
11/13/2002	**Water Temperature = 25 degrees C**			**$H = -\Sigma p_i * \ln p_i$**		
Phylum	**Common Name**	**Quantity**	**n_i**	**p_i**	**$\ln p_i$**	**$p_i * \ln p_i$**
Porifera	Heavenly/blue sponge	7	7			
	Green sponge	10	10			
	Red sponge	1	1			
	Purple sponge	11	11			
	Tube-unspecified	2	2			
Mollusca (Univalves)	Cerith	5	5			
	Top	15	15			
	Turban	2	2			
Mollusca (Bivalves)	Venus clam	1	1			
Arthropoda (shrimp)	Edible/pink shrimp	6	6			
	Mantis shrimp	12	12			
	Snapping/pistol shrimp	13	13			
Arthropoda (crabs)	Blue/swimming crab	23	23			
	Spider/decorator crab	14	14			
Arthropoda (other)	Florida lobster	3	3			
Chordata	Barracuda	1	1			
	File	1	1			
	Goby	10	10			
	Grunt	15	15			
	Parrot	12	12			
	Pipe	13	13			
	Puffer (checkered)	1	1			
	Sergeant major	3	3			
	Toad	3	3			
	TOTAL	184				
Species Richness =					**H =**	
Species Evenness = H/ln R						
Population Density =						

Catch Data from the Center For Environmental Education, Key Biscayne, FL				Shannon–Weiner Diversity Index		
5/2/2005	**Water Temperature = 24 degrees C**			**H = -Σ p_i * ln p_i**		
Phylum	**Common Name**	**Quantity**	**n_i**	**p_i**	**ln p_i**	**p_i * ln p_i**
Porifera	Heavenly/blue sponge	10	10			
	Brown sponge	2	2			
	Green sponge	5	5			
	Chicken liver sponge	3	3			
	Black/grey sponge	1	1			
Mollusca (Univalves)	Cerith	42	42			
	Top	47	47			
Annelida	Clam worm	1	1			
Arthropoda (shrimp)	Cleaning shrimp	2	2			
	Edible/pink shrimp	1	1			
	Arrow/grass shrimp	1	1			
	Mantis shrimp	3	3			
	Snapping/pistol shrimp	4	4			
Arthropoda (crabs)	Spider/decorator crab	3	3			
Echinodermata	Brittle star	1	1			
		1	1			
Chordata	File	1	1			
	Parrot	2	2			
	Pipe	7	7			
	Scorpion	2	2			
	Sea Horse	3	3			
	Toad	1	1			
	Wrasse	1	1			
	TOTAL	144				
Species Richness =					**H =**	
Species Evenness = H/ln R						
Population Density =						

Answer Sheet

Answer Sheet for Shannon–Wiener Diversity Index

Catch Data from the Center For Environmental Education, Key Biscayne, FL				Shannon–Weiner Diversity Index		
7/29/2002	**28 degrees C**	**92 cm**	**,l**	**H = -∑ p_i * ln p_i**		
Phylum	**Common Name**	**Quantity**	**n_i**	**p_i**	**ln p_i**	**p_i * ln p_i**
Porifera	Heavenly/blue sponge	2	2	0.0235294	-3.7495041	-0.0882236
	Chicken liver sponge	1	1	0.0117647	-4.4426513	-0.0522665
	Red sponge	2	2	0.0235294	-3.7495041	-0.0882236
Mollusca (Univalves)	Cerith	13	13	0.1529412	-1.8777019	-0.2871779
	Marginella	1	1	0.0117647	-4.4426513	-0.0522665
	Turban	13	13	0.1529412	-1.8777019	-0.2871779
	Drill	1	1	0.0117647	-4.4426513	-0.0522665
Arthropoda (shrimp)	Cleaning shrimp	1	1	0.0117647	-4.4426513	-0.0522665
	Edible/pink shrimp	1	1	0.0117647	-4.4426513	-0.0522665
	Mantis shrimp	3	3	0.0352941	-3.344039	-0.1180249
Arthropoda (crabs)	Blue/swimming crab	6	6	0.0705882	-2.6508918	-0.1871218
	Hermit crab	1	1	0.0117647	-4.4426513	-0.0522665
	Spider/decorator crab	3	3	0.0352941	-3.344039	-0.1180249
Arthropoda (other)	Florida lobster	1	1	0.0117647	-4.4426513	-0.0522665
Chordata	Goby	6	6	0.0705882	-2.6508918	-0.1871218
	Grunt	1	1	0.0117647	-4.4426513	-0.0522665
	Parrot	2	2	0.0235294	-3.7495041	-0.0882236
	Pipe	15	15	0.1764706	-1.7346011	-0.3061061
	Scorpion	1	1	0.0117647	-4.4426513	-0.0522665
	Snapper	3	3	0.0352941	-3.344039	-0.1180249
	Toad	3	3	0.0352941	-3.344039	-0.1180249
	Trunk (juv. - "pea fish")	5	5	0.0588235	-2.8332133	-0.1666596
	TOTAL	85				-2.628534
Species Richness = 22					**H = 2.6285**	
Species Evenness = H/ln R						
Population Density (individuals per m^2)=0.85						

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Catch Data from the Center For Environmental Education, Key Biscayne, FL				Shannon–Weiner Diversity Index		
11/13/2002	**25 degrees C**	**65.5 cm**		**$H = -\sum p_i * \ln p_i$**		
Phylum	**Common Name**	**Quantity**	**n_i**	**p_i**	**$\ln p_i$**	**$p_i * \ln p_i$**
Porifera	Heavenly/blue sponge	7	7	0.0380435	-3.2690256	-0.1243651
	Green sponge	10	10	0.0543478	-2.9123507	-0.1582799
	Red sponge	1	1	0.0054348	-5.2149358	-0.028342
	Purple sponge	11	11	0.0597826	-2.8170405	-0.16841
	Tube-unspecified	2	2	0.0108696	-4.5217886	-0.0491499
Mollusca (Univalves)	Cerith	5	5	0.0271739	-3.6054978	-0.0979755
	Top	15	15	0.0815217	-2.5068856	-0.2043657
	Turban	2	2	0.0108696	-4.5217886	-0.0491499
Mollusca (Bivalves)	Venus clam	1	1	0.0054348	-5.2149358	-0.028342
Arthropoda (shrimp)	Edible/pink shrimp	6	6	0.0326087	-3.4231763	-0.1116253
	Mantis shrimp	12	12	0.0652174	-2.7300291	-0.1780454
	Snapping/pistol shrimp	13	13	0.0706522	-2.6499864	-0.1872273
Arthropoda (crabs)	Blue/swimming crab	23	23	0.125	-2.0794415	-0.2599302
	Spider/decorator crab	14	14	0.076087	-2.5758784	-0.1959907
Arthropoda (other)	Florida lobster	3	3	0.0163043	-4.1163235	-0.067114
Chordata	Barracuda	1	1	0.0054348	-5.2149358	-0.028342
	File	1	1	0.0054348	-5.2149358	-0.028342
	Goby	10	10	0.0543478	-2.9123507	-0.1582799
	Grunt	15	15	0.0815217	-2.5068856	-0.2043657
	Parrot	12	12	0.0652174	-2.7300291	-0.1780454
	Pipe	13	13	0.0706522	-2.6499864	-0.1872273
	Puffer (checkered)	1	1	0.0054348	-5.2149358	-0.028342
	Sergeant major	3	3	0.0163043	-4.1163235	-0.067114
	Toad	3	3	0.0163043	-4.1163235	-0.067114
	TOTAL	184				-2.8554853
Species Richness = 24					**H = 2.8555**	
Species Evenness = H/ln R						
Population Density (individuals per m^2)=1.84						

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Catch Data from the Center For Environmental Education, Key Biscayne, FL				Shannon–Weiner Diversity Index		
5/2/2005	**24 degrees C**			**$H = -\sum p_i * \ln p_i$**		
Phylum	**Common Name**	**Quantity**	**n_i**	**p_i**	**$\ln p_i$**	**$p_i * \ln p_i$**
Porifera	Heavenly/blue sponge	10	10	0.0694444	-2.6672282	-0.1852242
	Brown sponge	2	2	0.0138889	-4.2766661	-0.0593981
	Green sponge	5	5	0.0347222	-3.3603754	-0.1166797
	Chicken liver sponge	3	3	0.0208333	-3.871201	-0.08065
	Black/grey sponge	1	1	0.0069444	-4.9698133	-0.0345126
				0		
Mollusca (Univalves)	Cerith	42	42	0.2916667	-1.2321437	-0.3593752
	Top	47	47	0.3263889	-1.1196657	-0.3654464
				0		
Annelida	Clam worm	1	1	0.0069444	-4.9698133	-0.0345126
				0		
Arthropoda (shrimp)	Cleaning shrimp	2	2	0.0138889	-4.2766661	-0.0593981
	Edible/pink shrimp	1	1	0.0069444	-4.9698133	-0.0345126
	Arrow/grass shrimp	1	1	0.0069444	-4.9698133	-0.0345126
	Mantis shrimp	3	3	0.0208333	-3.871201	-0.08065
	Snapping/pistol shrimp	4	4	0.0277778	-3.5835189	-0.0995422
				0		
Arthropoda (crabs)	Spider/decorator crab	3	3	0.0208333	-3.871201	-0.08065
				0		
Echinodermata	Brittle star	1	1	0.0069444	-4.9698133	-0.0345126
		1	1	0.0069444	-4.9698133	-0.0345126
				0		
Chordata	File	1	1	0.0069444	-4.9698133	-0.0345126
	Parrot	2	2	0.0138889	-4.2766661	-0.0593981
	Pipe	7	7	0.0486111	-3.0239032	-0.1469953
	Scorpion	2	2	0.0138889	-4.2766661	-0.0593981
	Sea Horse	3	3	0.0208333	-3.871201	-0.08065
	Toad	1	1	0.0069444	-4.9698133	-0.0345126
	Wrasse	1	1	0.0069444	-4.9698133	-0.0345126
	TOTAL	144				-2.144069
Species Richness = 24						
Species Evenness = H/ln R						
Population Density (individuals per m^2)=1.44						

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Additional Web Sites

www.myfootprint.org

http://esa21.kennesaw.edu/activities/ecol-foot/ecol-foot.pdf *Ecological Footprint Calculator; ESA 21 — Environmental Science Activities for the 21st Century; activities involving ecological footprint calculations.*

http://www.sbs.utexas.edu/resource/EcoFtPrnt/9-20-00ef_household_evaluation.xls *Ecological Footprint Calculator* (spreadsheet).

About the Editor

Scottie Smith is the upper-school principal and AP Environmental Science teacher at the Canterbury School of Florida in St. Petersburg, Florida. Smith received her B.S. in microbiology from Auburn University in 1988 and her Ph.D. in microbiology from Texas A&M University in 1993. She was an adjunct professor at the University of Tampa teaching environmental science for several years. She has been teaching AP Environmental Science since 1998 and has been an AP Reader since 1999. She has served as an AP Table Leader since 2003. She has been an AP consultant since 2001, presenting workshops and weeklong institutes. Smith is actively involved in preparing students for the Envirothon, North America's largest environmental competition. Her 1999 and 2003 teams were the Florida Envirothon champions.

About the Authors

Mark Ewoldsen has bachelor's degrees in biology and in chemistry, a master's degree in educational administration, and a Ph.D. in biochemistry. He has done research on the immunology of reproduction at Iowa State University, the immunology of melanoma at Norris Cancer Center–University of Southern California, and environmental studies of the Amazon Basin at the Jet Propulsion Laboratory/NASA. Ewoldsen has been a full-time teacher at La Cañada High School since 1990 and has taught part-time at community colleges and universities. He has been teaching AP Environmental Science since 2000 and has participated at the AP Readings since 2006. In 1996, he initiated his Web site and has spent considerable time trying to make it useful for students and teachers (http://www.lcusd.net/lchs/mewoldsen). Ewoldsen and his Paulla, have two children.

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Sarah Utley is the AP Environmental Science teacher at Beverly Hills High School in Beverly Hills, California. She received her B.S. in plant biology from the University of Illinois at Urbana-Champaign in 1993 and worked as a field botanist for the National Park Service at both Yellowstone National Park and Canyonlands National Park. She then returned to the University of Illinois and received her M.S. in biology with an emphasis on teaching in 1997. Since 1998 she has created and taught the AP Environmental Science course at two different high schools. Utley also developed the curriculum (content, laboratory assignments, and assessments) for UCLA's Center for Digital Innovation's online AP Environmental Science course. She has worked as an AP Reader and Table Leader for the College Board since 2003. She contributed to and edited the Barron's *AP Environmental Science Test Preparation Guide*, 2nd edition. In addition to full-time teaching, Utley is the school's accreditation co-chair and is currently pursuing an M.A. in educational administration.

Kathryn Weatherhead received a B.S. in biology from Mary Washington College in 1977, and an M.A.T. in biology in 1979 from the University of South Carolina, where she taught biology and nursing school for two years. Weatherhead is science department chairman at Hilton Head Island High School in Hilton Head Island, South Carolina, where she has lived and taught since 1980. She has served as assistant professor of biology and marine science at the University of South Carolina Beaufort since 1998, and an adjunct professor at Winthrop University since 1990. She is National Board–certified in science, has been an AP Biology Reader and AP consultant since 1992. She and received APES training at University of Arkansas in 1997, leaving biology to become an AP Environmental Science Reader and Table Leader in 2004. She gives numerous workshops and summer institutes in both AP Biology and Environmental Science serves as a textbook evaluator and product development consultant, and coauthored *Advanced Environmental Science*.

Carol Widegren has been teaching AP science classes at Lincoln Park High School (Chicago Public Schools) since 1991. Lincoln Park High School has been recognized by *U.S. News & World Report* and *Newsweek* for the rigorous curriculum to which the students are exposed, particularly the Advanced Placement Program®. Widigren earned her B.S. in biology (1973) and M.A. in environmental science (1976) from Northeastern Illinois University, and holds an M.Ed. in educational leadership and organizational change (2002) from Roosevelt University. Widigren has been a College Board consultant since 1996, presenting workshops and weeklong institutes in the Midwest and North Carolina. Widigren has served as both an AP Environmental Science Reader and Table Leader.