4

The Inhabitants of Planet Earth and Their Relationships

According to the College Board, about 10–15 percent of the questions you'll see on the AP Environmental Science Exam can be classified under the broad topic "The Living World." In this chapter, we'll cover everything you'll need to know to tackle these questions.

As you probably learned in your biology class, the nonliving components of Earth are known as its abiotic components. These include the atmosphere, hydrosphere, and lithosphere—the things we studied in the last chapter. In this chapter, we'll talk about the biotic, or living components, of Earth. We'll start by discussing elements that bridge the gap between the nonliving and the living—water, nitrogen, carbon, and phosphorus—and how they cycle through the environment. We'll then move on to a discussion of what types of ecosystems exist and how they're structured. We'll continue our review by discussing how energy flows through ecosystems, and we'll end the chapter with a review of how ecosystems change. Let's begin!

CYCLES IN NATURE

As you may have learned in your biology class, nutrients such as carbon, oxygen, nitrogen, phosphorus, sulfur, and water all move through the environment in complex cycles known as **biogeochemical cycles.** Well, you'll need to know a bit about these cycles for the exam, so we'll go through each of them here.

As you can probably tell from the collective name of these natural cycles, living organisms, geologic formations, and chemical substances are all involved in these cycles. Keep in mind that when we describe the movement of these inorganic compounds, it's important to understand both the destinations of the compounds and how they move toward their destinations. For example, for the AP Environmental Science test, it won't be enough for you to know that water moves from the atmosphere to the earth. You'll need to know the different ways it has of getting there. In other words, you'll need to know that water moves from the atmosphere to the earth's surface through precipitation, either in the form of snow or rainfall.

But, let's talk about a few things that all of these cycles have in common before we go into each one in detail. First of all, the term **reservoir** is used to describe a place where a large quantity of a nutrient sits for a long period of time (in the water cycle, the ocean is an example of a reservoir). The opposite of a reservoir is an **exchange pool,** which is a site where a nutrient sits for only a short period of time (in the water cycle, a cloud is an example of an exchange pool). The amount of time a nutrient spends in a reservoir or an exchange pool is called its **residency time.** In the water cycle, water might exist in the form of a cloud for a few days, but it might exist as part of the ocean for a thousand years! Perhaps surprisingly, living organisms can also serve as exchange pools and reservoirs for certain nutrients; we'll delve into more about this later.

The energy that drives these biogeochemical cycles in the biosphere comes primarily from two sources: the sun, and the heat energy from the mantle and core of the earth. The movements of nutrients in all of these cycles may be via abiotic mechanisms, such as wind, or may occur through biotic mechanisms, such as through living organisms (as we mentioned earlier). Another important fact to note is that while the **Law of Conservation of Matter** states that matter can neither be created nor destroyed, nutrients can be rendered unavailable for cycling through certain processes—for example, in some cycles, nutrients may be transported to deep ocean sediments where they are locked away interminably.

Though we won't get into a discussion of trace elements here, you should also know that certain trace elements such as zinc, copper, and iron are necessary in small amounts for living organisms. Trace elements can cycle in conjunction with the major nutrients, but there's still much to be discovered about these elements and their biogeochemical cycles. For this exam, just know that there are certain trace elements required by living things that cycle, along with the major elements, through the biosphere.

Let's start with perhaps the best-known biogeochemical cycle: the water cycle.

The Water Cycle

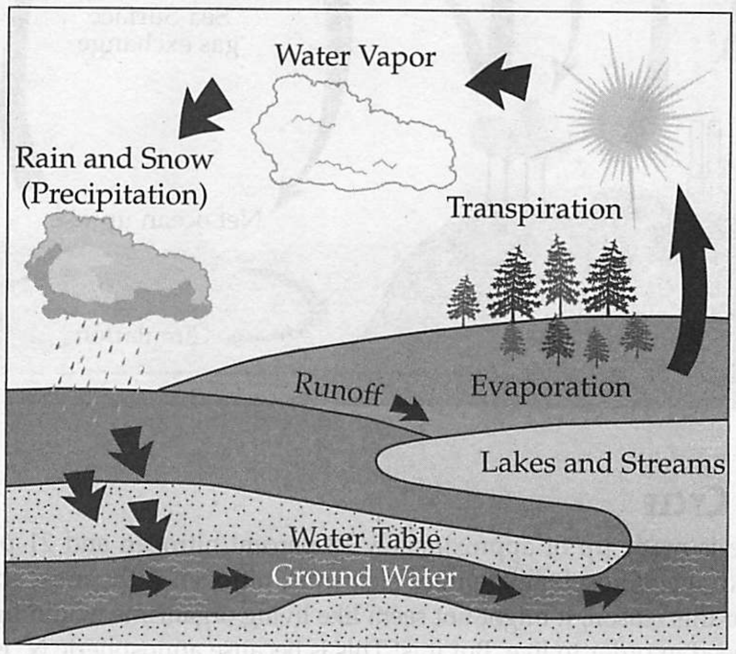
As you might imagine, the water that exists in the atmosphere is in a gaseous state, and when it condenses from the gaseous state to form a liquid or solid, it becomes dense enough to fall to the earth because of the pull of gravity. This process is formally known as **precipitation.** When precipitation falls onto the earth, it may travel below ground to become **groundwater,** or it may travel across the land's surface as **runoff** and enter a drainage system, such as a stream or river, that will eventually deposit it into a body of water such as a lake or an ocean. Lakes and oceans are reservoirs for water. In certain cold regions of Earth, water may also be trapped on the earth's surface as snow or ice; in these areas, the blocks of snow or ice are reservoirs.

Water is also cycled through living systems. For example, plants consume water (and carbon dioxide) in the process of photosynthesis, in which they produce carbohydrates. Because all living organisms are primarily made up of water, they act as exchange pools for water.

Water is returned to the atmosphere from both the earth's surface and from living organisms in a process called **evaporation.** Specifically, animals respire and release water vapor and additional gases to the atmosphere. In plants, the process of **transpiration** releases large amounts of water into the air. Finally, other major contributors to atmospheric water are the vast number of lakes and oceans on Earth's surface. Incredibly large amounts of water continually evaporate from their surfaces.

Take a look at the graphic below, which shows all of the forms that water takes in the biosphere and atmosphere.

The Water Cycle



The Carbon Cycle

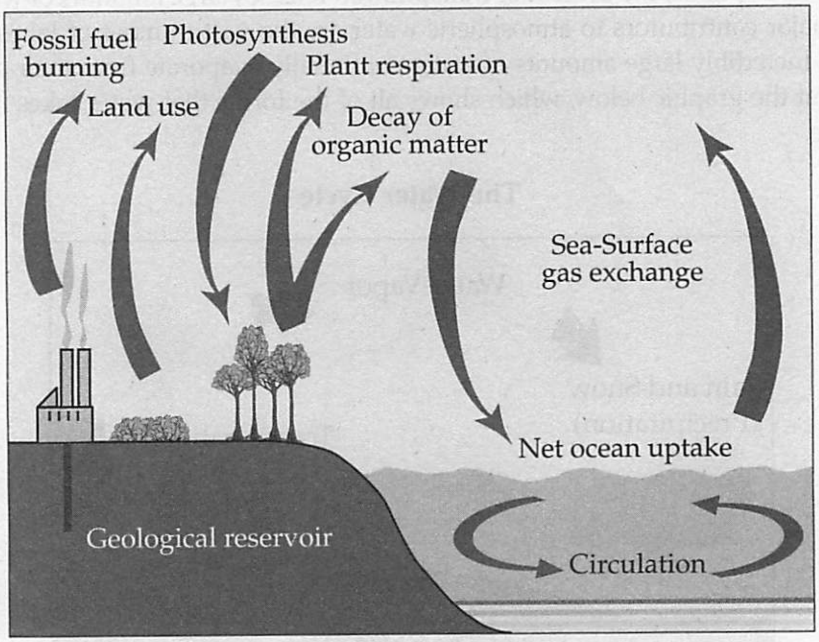
Now let's talk about carbon. The key events in the carbon cycle are **respiration,** in which animals (and plants!) breathe and give off carbon dioxide; and **photosynthesis,** in which plants take in carbon dioxide, water, and energy from the sun to produce carbohydrates. In other words, living things act as exchange pools for carbon.

When plants are eaten by animal consumers, the carbon locked in the plant carbohydrates passes to other organisms and continues through the food chain (more on this later in the chapter). In turn, when organisms—both plants and animals—die, their bodies are decomposed through the actions of bacteria and fungi in the soil; this releases CO_2 back into the atmosphere.

One aspect of the carbon cycle that you should definitely be familiar with for the exam is this: When the bodies of once-living organisms are buried and subjected to conditions of extreme heat and extreme pressure, eventually this organic matter becomes oil, coal, and gas. Oil, coal, and natural gas are collectively known as fossil fuels, and when fossil fuels are burned, or **combusted,** carbon is released into the atmosphere. Finally, carbon is also released into the atmosphere through volcanic action.

There are two major reservoirs of carbon; the first is the world's oceans, because CO_2 is very soluble in water. The second large reservoir of CO_2 is Earth's rocks. Many types of rocks—called carbonate rocks—contain carbon, in the form of calcium carbonate.

The Carbon Cycle



The Nitrogen Cycle

Earth's atmosphere is made up of approximately 78 percent nitrogen and 21 percent oxygen (the other components of the atmosphere are trace elements); nitrogen is the most abundant element in the atmosphere. For this reason, it might not seem like living organisms would find it difficult to get the nitrogen they need in order to live. But it is! This is because atmospheric N_2 is not in a form that can be used directly by most organisms. In order to keep this rather complicated cycle straight, let's look at it in steps.

Step 1: **Nitrogen fixation**—In order to be used by most living organisms, nitrogen must be present in the form of ammonia (NH_3) or nitrates (NO_3^-). Atmospheric nitrogen can be converted into these forms, or "fixed," by atmospheric effects such as lightning storms, but most nitrogen fixation is the result of the actions of certain soil bacteria. One important soil bacteria that participates in nitrogen fixation is *Rhizobium*. These nitrogen-fixing bacteria are often associated with the roots of legumes such as beans or clover. In the future we may be able to insert the genes for nitrogen fixation into crop plants, such as corn, and reduce the amount of fertilizer that is used.

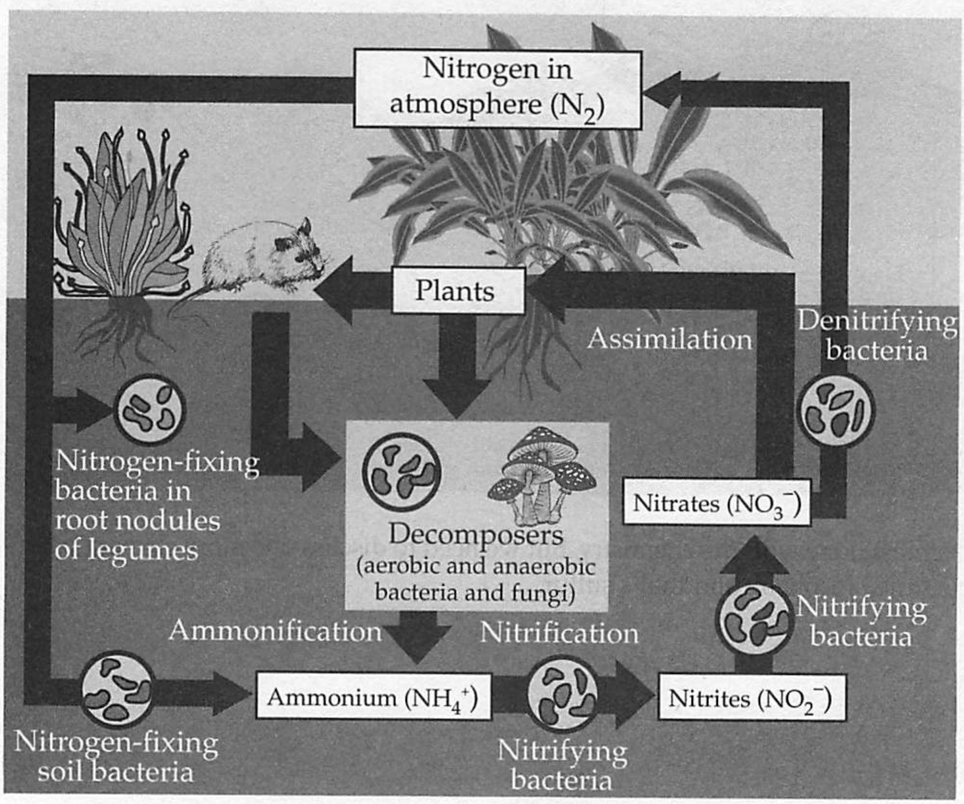
Step 2: **Nitrification**—In this process, soil bacteria converts ammonium (NH_4^+) into one of the forms that can be used by plants—nitrate (NO_3).

Step 3: **Assimilation**—In assimilation, plants absorb ammonium (NH_3), ammonia ions (NH_4^+), and nitrate ions (NO_3^-) through their roots. Heterotrophs then obtain nitrogen when they consume plants' proteins and nucleic acids.

Step 4: **Ammonification**—In this process, decomposing bacteria convert dead organisms and other waste to ammonia (NH_3) or ammonium ions (NH_4^+), which can be reused by plants.

Step 5: **Denitrification**—In denitrification, specialized bacteria (mostly anaerobic bacteria) convert ammonia back into nitrites and nitrates and then into nitrogen gas (N_2) and nitrous oxide gas (N_2O). These gases then rise to the atmosphere.

The Nitrogen Cycle



The Phosphorus Cycle

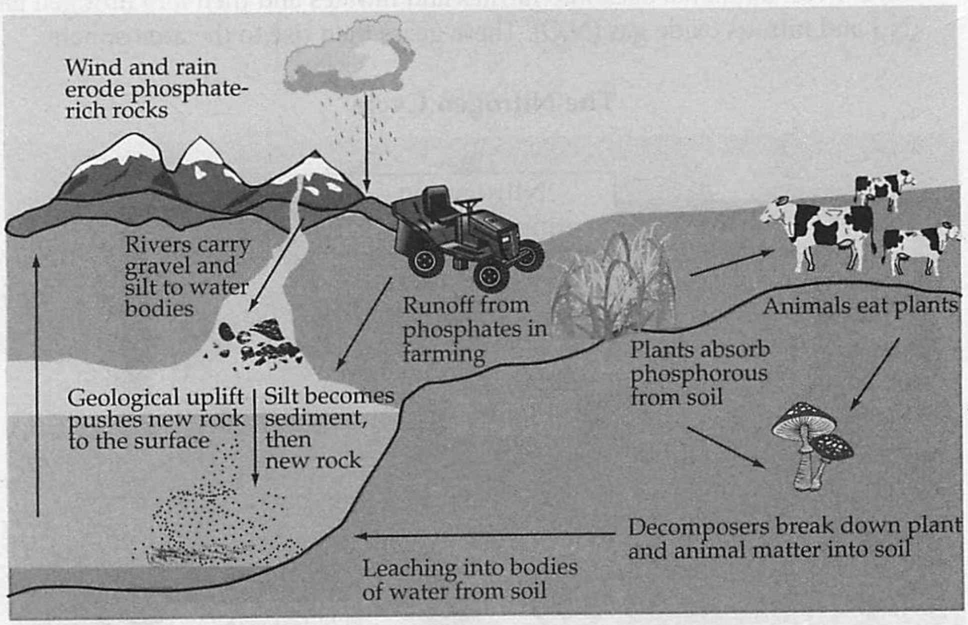
The **phosphorus cycle** is perhaps the simplest biogeochemical cycle, mostly because phosphorus does not exist in the atmosphere outside of dust particles. Phosphorus is necessary for living organisms because it's a major component of nucleic acids and other important biological molecules. One important idea for you to remember about the phosphorus cycle is that phosphorus cycles are more local than those of the other important biological compounds.

For the most part, phosphorus is found in soil, rock, and sediments; it's released from these rock forms through the process of chemical weathering. Phosphorus is usually released in the form of phosphate (PO_4^{3-}), which is very soluble and can be absorbed from the soil by plants. You should know that phosphorus is also often a limiting factor for plant growth, so plants that have little phosphorus are stunted.

Phosphates that enter the water table and travel to the oceans can eventually be incorporated into rocks in the ocean floor. Through geologic processes, ocean mixing, and upwelling, these rocks from the seafloor may rise up so that their components once again enter the **terrestrial cycle.** Take a look at the phosphorus cycle shown in the diagram below.

Humans have affected the phosphorus cycle by mining phosphorus-rich rocks in order to produce fertilizers. The fertilizers placed on fields can easily leach into the groundwater and find their way into aquatic ecosystems where they can cause eutrophication and overgrowth of algae.

The Phosphorous Cycle



We are almost done with the chemistry. But we need to discuss one more element before we move on to discuss the biosphere, and that's sulfur.

Sulfur

The last biogeochemical cycle we'll talk about is the phosphorus cycle. Sulfur is one of the components that make up proteins and vitamins, so plants and animals both need sulfur in their diets. Plants absorb sulfur when it is dissolved in water, so they can take it up through their roots when it's dissolved in groundwater. Animals obtain sulfur by consuming plants.

Most of the earth's sulfur is tied up in rocks and salts or buried deep in the ocean in oceanic sediments, but some sulfur can be found in the atmosphere. The natural ways that sulfur enters the atmosphere are through volcanic eruptions, certain bacterial functions, and the decay of once-living organisms. When sulfur enters the atmosphere through human activity, it's mainly via industrial processes that produce sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) gases. We'll talk more about sulfur and how it contributes to air pollution in Chapter 8.

All right! It's time to move on to our discussion of the biotic components of Earth. Let's start with a review of how energy moves through ecosystems.

FOOD CHAINS AND FOOD WEBS

You might recall that the nonliving components of the environment are known as the abiotic components. These include the atmosphere, hydrosphere, and lithosphere. Remember them from Chapter 3? Well, it's time to begin our study of the living, biotic components of Earth. Together, all of the living things on Earth constitute the biosphere.

All living things can be classified by how they obtain food. You might recall that plants and some caynobacteria are capable of making their own food through photosynthesis, and that some animals (for example, mice) eat plants. Some animals (for example, humans) eat both plants and animals, and some animals (for example, wolves) eat only other animals. There are actually two fancy terms that are normally used to describe these broad categories of organisms: **Autotrophs** are those organisms that can produce their own organic compounds from inorganic chemicals, while **heterotrophs** obtain food energy by consuming other organisms or products created by other organisms.

Finally, as unpleasant as it might be to think about, some animals feed only on the remains of other plants and animals! All of these different types of living things fall into specific categories—and you will definitely need to memorize all of these terms before the test, if you don't already know them!

Producers

Producers are organisms that are capable of converting radiant energy or chemical energy into carbohydrates. The group of producers includes plants and algae, both of which can carry out photosynthesis. The unbalanced overall reaction of photosynthesis is shown below.

$$H_2O + CO_2 + \text{solar energy} \rightarrow CH_2O + O_2$$

While most producers make food through photosynthesis, a few autotrophs make food from inorganic chemicals in anaerobic (without oxygen) environments, through the process of chemosynthesis. Chemosynthesis is only carried out by a few specialized bacteria, called **chemotrophs**, some of which are found in hydrothermal vents deep in the ocean. This unbalanced reaction is shown below.

$$O_2 + H_2S + O_2 + \text{energy} \rightarrow CH_2O + S + H_2O$$

At this point, let's discuss a few other environmental science terms that you'll be required to know for the exam. The **Net Primary Productivity** (**NPP**) is the amount of energy that plants pass on to the community of herbivores in an ecosystem. It is calculated by taking the **Gross Primary Productivity,** which is the amount of sugar that the plants produce in photosynthesis, and subtracting from it the amount of energy the plants need for growth, maintenance, repair, and reproduction. NPP is measured in kilocalories per square meter per year (kcal/m^2/y). In other words, the gross primary productivity of an ecosystem is the rate at which the producers are converting solar energy to chemical energy (or, in a hydrothermal ecosystem, the rate of productivity of the chemotrophs). Perhaps not surprisingly, the net productivity of an ecosystem is a limiting factor for its number of consumers. Let's talk about them next.

Consumers

Consumers are organisms that must obtain food energy from secondary sources, for example, by eating plant or animal matter. There are a number of different types of consumers, and we've listed them below. Commit these to memory!

- **Primary consumers:** This category includes the herbivores, which consume only producers (plants and algae).
- **Secondary consumers:** An organism that consumes a primary consumer is as secondary consumer.
- **Tertiary consumers:** An organism that consumes a secondary consumer is a tertiary consumer.
- **Detritivores:** The organisms in this group derive energy from consuming nonliving organic matter such as dead animals or fallen leaves.
- **Decomposers:** These are bacteria or fungi that absorb nutrients from nonliving organic matter such as plant material, the wastes of living organisms, and corpses. They convert these materials into inorganic forms.

Note that one organism may occupy multiple levels of a food chain. By eating a hamburger with toppings you are both a primary consumer because you are eating tomatoes and lettuce, and a secondary consumer by eating the beef.

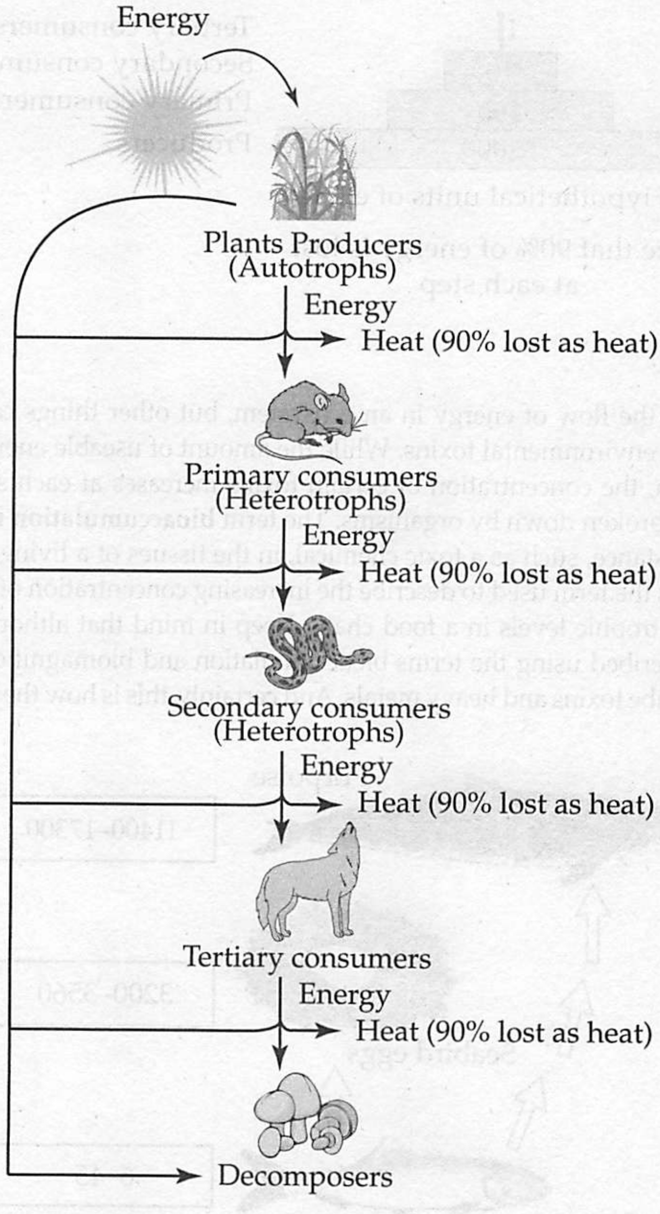
Let's move on and talk about how energy flows through all of these different types of organisms in ecosystems.

Food Chains

As you probably recall, energy flows in one direction through ecosystems: from the sun to producers, to primary consumers, to secondary consumers, to tertiary consumers. In an ecosystem, each of these feeding levels is referred to as a **trophic level**. With each successive trophic level, the amount of energy that's available to the next level decreases. In fact, only about 10 percent of the energy from one trophic level is passed to the next; most is lost as heat, and some is used for metabolism and anabolism. Interestingly enough, this is why food chains rarely have more than four trophic levels.

Food chains are usually represented as a series of steps, in which the bottom step is the producer and the top step is a secondary or tertiary consumer. In food chains, the arrows depict the transfer of energy through the levels, and in fancier food chains, the relative biomass (the dry weight of the group of organisms) of each trophic level will often be represented. Here's a simple food chain.

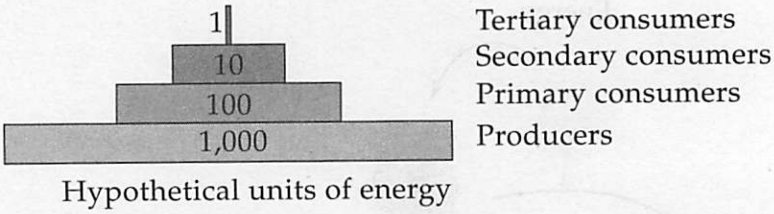
Food Chain



What we're showing here is a typical terrestrial food chain, but keep in mind that there are aquatic food chains as well, with algae and different types of fish.

One final note about food chains: In a food chain, only about 10 percent of the energy is transferred from one level to the next. The other 90 percent is used for things like respiration, digestion, running away from predators—that is, it's used to power the organism doing the eating! In other words, the producers have the most energy in an ecosystem; the primary consumers have less energy than producers; the secondary consumers have less energy than the primary consumers; and the tertiary consumers will have the least energy of all. The amount of energy (in kilocalories) available at each trophic level organized from greatest to least is an **energy pyramid**, as seen on the next page.

Energy Pyramid

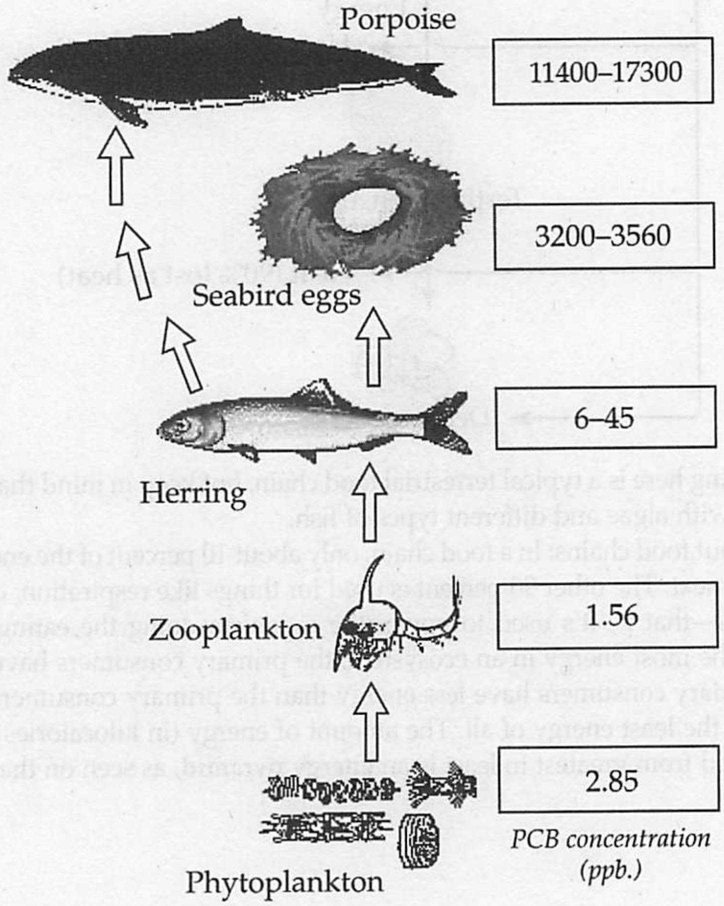


Note that 90% of energy is lost at each step

Biomagnification

Food chains represent the flow of energy in an ecosystem, but other things can flow through food chains, too—including environmental toxins. While the amount of useable energy decreases at every level of the food chain, the concentration of certain toxins increases at each successive level, since most toxins cannot be broken down by organisms. The term **bioaccumulation** is used to describe the accumulation of a substance, such as a toxic chemical, in the tissues of a living organism.

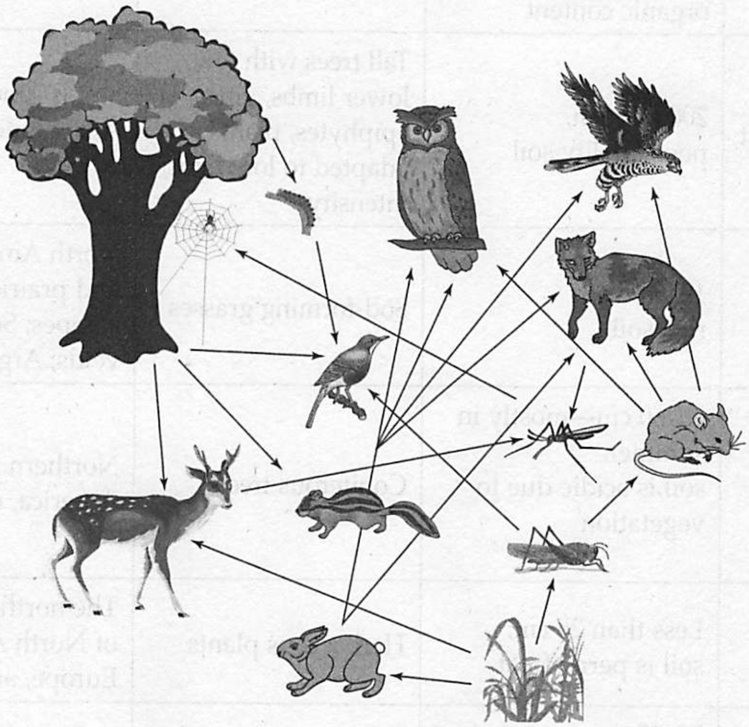
Biomagnification is the term used to describe the increasing concentration of these toxin molecules at successively higher trophic levels in a food chain. Keep in mind that although really any type of molecule could be described using the terms bioaccumulation and biomagnification, generally these terms are used to describe toxins and heavy metals. And certainly, this is how they'll be used on the test.



Food Webs — Tangled Food Chains

As you're probably already aware, food chains are an oversimplified way of demonstrating the myriad feeding relationships that exist in ecosystems. Because there are so many different types of species of plants and animals in ecosystems, their relationships in real-world ecosystems are much more complicated than can be depicted in a single food chain. Therefore, we use a **food web** in order to represent feeding relationships in ecosystems more realistically.

Food Web



Again, this is a typical terrestrial food web, but keep in mind that very complicated aquatic food webs exist as well! Let's take a step back for a minute and discuss the setting for food chains and food webs—ecosystems.

THE WORLD'S ECOSYSTEMS

Because different geographic areas on Earth differ so much in their abiotic and biotic components, we can easily place them in broad categories. The two largest categories are broken down in this way: Ecosystems that are based on land are called **biomes,** while those in aqueous environments are known as **aquatic life zones.** Aquatic ecosystems are categorized primarily by the salinity of their water—freshwater and saltwater ecosystems fall into separate categories. Land environments are separated into biomes based on their climate (remember temperature and precipitation!).

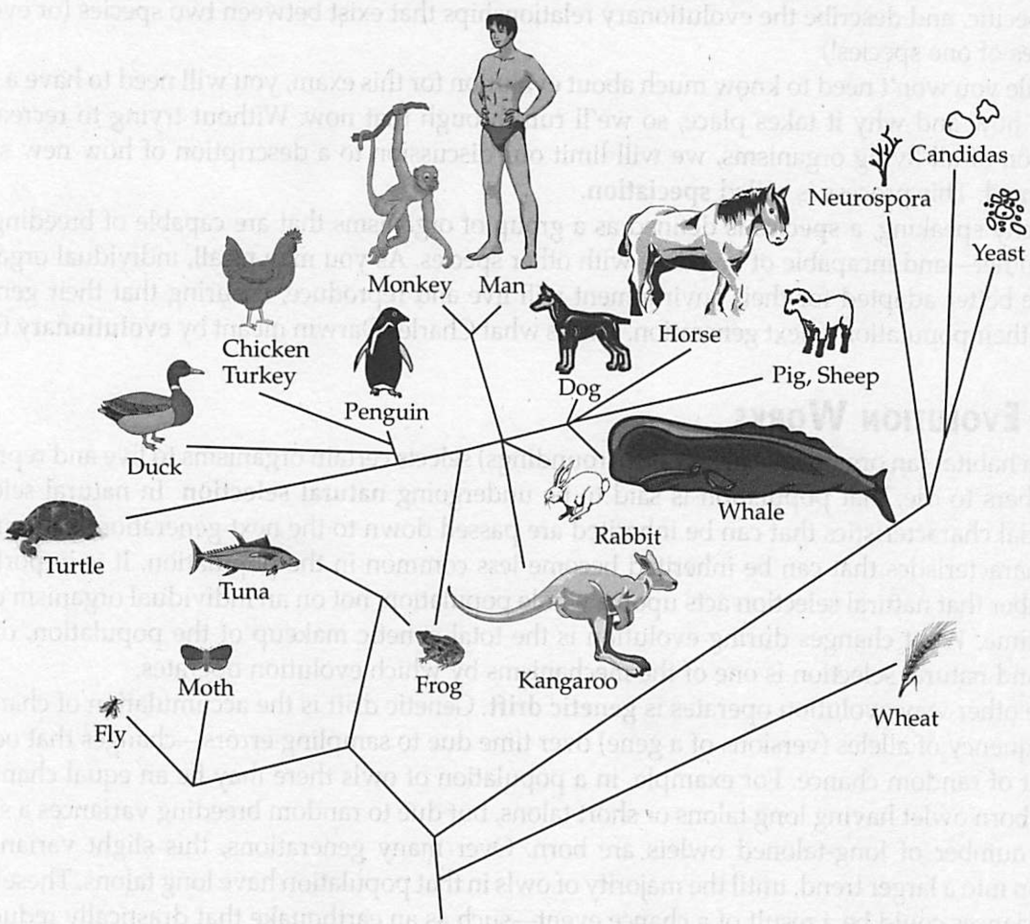
Although it might seem that each biome listed in the table on the following page is very distinct, in reality, biomes blend into each other; they do not have distinct boundaries. The transitional area where two ecosystems meet actually has a name—these areas are called **ecotones.** Another important term that you should be familiar with for the exam is **ecozones:** Ecozones (also called **ecoregions**) are smaller regions within ecosystems that share similar physical features. Here's that table.

Biome	Annual Rainfall, Soil Type	Major Vegetation	World Location
Deciduous forest (temperate and tropical)	75–250 cm, rich soil with high organic content	Hardwood trees	North America, Europe, Australia, and Eastern Asia
Tropical rainforest	200–400 cm, poor quality soil	Tall trees with few lower limbs, vines, epiphytes, plants adapted to low light intensity	South America, West Africa, and Southeast Asia
Grasslands	10–60 cm, rich soil	Sod-forming grasses	North American plains and prairies; Russian steppes; South African velds; Argentinean pampas
Coniferous forest (Taiga)	20–60 cm—mostly in summer, soil is acidic due to vegetation	Coniferous trees	Northern North America, northern Eurasia
Tundra	Less than 25 cm, soil is permafrost	Herbaceous plants	The northern latitudes of North America, Europe, and Russia
Chaparral (scrub forest)	50–75 cm—mostly in winter, soil is shallow and infertile	Small trees with large hard leaves, spiny shrubs	Western North America, the Mediterranean region
Deserts (cold and hot)	Less than 25 cm, soil has a course texture (i.e., sandy)	Cactus, other low-water adapted plants	30 degrees north and south of the equator

Not surprisingly, each biome has specific characteristics that determine the types of organisms that are capable of living in it. Some of these characteristics are the type and availability of nutrients, the ecosystems' temperature, the availability of water, and how much sunlight the region receives. One important law to be familiar with for this test is the **Law of Tolerance.** The Law of Tolerance describes the degree to which living organisms are capable of tolerating changes in their environment. Living organisms exhibit a range of tolerance, and even individuals within a population tolerate changes to their environment differently: This concept is the basis for natural selection, which drives evolution (more on this later in the chapter).

Another important law for you to know is the **Law of the Minimum,** which states that living organisms will continue to live, consuming available materials until the supply of these materials is exhausted.

Philogenetic Tree



Ecosystem Diversity

The term **biodiversity** is used to describe the number and variety of organisms found within a specified geographic region, or ecosystem. It also refers to the variability among living organisms, including the variability within and between species and within and between ecosystems.

Therefore, when we talk about the biodiversity of an area, we must specify the aspect of biodiversity that we're describing, or else the term is too vague to be comprehensible. In general, however, biodiversity in an ecosystem is a good thing. The more biodiversity in a certain species within an ecosystem, the larger and more diverse the species' gene pool, and the greater its chance of adaptation, and thus survival.

EVOLUTION

Biodiversity in all forms is the result of **evolution.** Evolution is the change in a population's genetic composition over time.

We use a figure called a **phylogenetic tree** to model evolution. Phylogenetic trees can be very broad, like the one on the previous page, which encompasses many types of species, or they can be very specific, and describe the evolutionary relationships that exist between two species (or even the genomes of one species!)

While you won't need to know much about evolution for this exam, you will need to have a rough idea of how and why it takes place, so we'll run through that now. Without trying to recreate the evolution of all living organisms, we will limit our discussion to a description of how new species are formed. This process is called **speciation.**

Strictly speaking, a **species** is defined as a group of organisms that are capable of breeding with one another—and incapable of breeding with other species. As you may recall, individual organisms that are better adapted for their environment will live and reproduce, ensuring that their genes are part of their population's next generation. This is what Charles Darwin meant by **evolutionary fitness.**

How Evolution Works

When a habitat (an organism's physical surroundings) selects certain organisms to live and reproduce and others to die, that population is said to be undergoing **natural selection.** In natural selection, beneficial characteristics that can be inherited are passed down to the next generation, and unfavorable characteristics that can be inherited become less common in the population. It is important to remember that natural selection acts upon a whole population, not on an individual organism during its lifetime. What changes during evolution is the total genetic makeup of the population, or **gene pool,** and natural selection is one of the mechanisms by which evolution operates.

The other way evolution operates is **genetic drift.** Genetic drift is the accumulation of changes in the frequency of alleles (versions of a gene) over time due to sampling errors—changes that occur as a result of random chance. For example, in a population of owls there may be an equal chance of a newly born owlet having long talons or short talons, but due to random breeding variances a slightly larger number of long-taloned owlets are born. Over many generations, this slight variance can develop into a larger trend, until the majority of owls in that population have long talons. These breeding variances could be a result of a chance event—such as an earthquake that drastically reduces the size of the nesting population one year. Small populations are more sensitive to the effects of genetic drift than large, diverse populations.

When a population displays small scale changes over a relatively short period of time, **microevolution** has occurred. **Macroevolution** refers to large-scale patterns of evolution within biological organisms over a long period of time.

Just as new species are formed by natural selection and genetic drift, other species may become extinct. **Extinction** occurs when a species cannot adapt quickly enough to environmental change and all members of the species die.

Relationships Between Species

Let's talk more about how species get along together in ecosystems. You probably recall from your biology class that a group of organisms of the same species is called a **population,** and when populations of different species occupy the same geographic area, they form a **community.** Every species within a community has an ecological niche. A species' **niche** is described as the total sum of a species' use of the biotic and abiotic resources in its environment. The niche describes where the species lives, what it eats, and all of the other resources the species utilizes in an ecosystem. Another term you should know for the exam is habitat—a **habitat** is the area or environment where an organism or ecological community normally lives or occurs.

Some species interact quite a bit with other members of their population; for example, some animals form herds, while other species are loners—like bears. The reasons for these different levels of sociability are largely competition, predation, and a general need to exploit the resources in the environment.

Competition arises when two individuals—of the same species or of different species—are competing for resources in the environment. When the two individuals that are competing are of the same species, this is called **intraspecific competition,** and when they are of different species, it's called **interspecific competition.** The resources that are competed for can be food, air, shelter, sunlight, and various other factors necessary for life; individuals may be competing to live in a fallen tree, to catch a running rabbit, or to mate with the most desirable female in the population. The competitor who is "most fit" eventually wins and obtains the resource. That's right—the others are eliminated by competition.

One more thing about competition: When two different species in a region compete, and the better adapted species wins, this phenomenon is called **competitive exclusion. Gause's principle** states that no two species can occupy the same niche at the same time, and that the species that is less fit to live in the environment will relocate, die out, or occupy a smaller niche. When a species occupies a smaller niche than it would in the absence of competition, this compromised niche is called its **realized niche.** (The niche it would have if there were no competition is known as its **fundamental niche.**) All right, moving on!

Although it's relatively easy to observe competition between animals, competition between plants is much more subtle and occurs much more slowly. However, if you have a few years to kill, spend some time in your backyard watching the trees and other plants grow. You'll see that they compete for sunlight and for ground space; they even produce chemicals that inhibit other plants' growth!

The second important type of interspecies interaction is predation. **Predation** occurs when one species feeds on another, and it is the force that drives changes in population size. For example, in a year in which rainfall is relatively high in some regions, rabbits have plenty of food; this enables them to reproduce very successfully, and the number of rabbits in a population will increase dramatically. In turn, if the coyote is a predator of the rabbit, coyotes will have plenty of food, and their population will also boom. However, if the following year the rainfall is below average, there will be less grass; the population of rabbits will decline, and this will result in a decline in the population of coyotes. As a final note about predation: While it's tempting to think of predation existing only between animals, remember that herbivores prey on plants and zooplankton on phytoplankton!

A third type of relationship that exists between organisms is the symbiotic relationship. **Symbiotic relationships** are close, prolonged associations between two or more different organisms of different species that may, but do not necessarily, benefit each member. There are three types of symbiotic relationships, and you should be familiar with all of these for exam day. In mutualistic symbiotic relationships **(mutualism)** both species benefit; for example, this type of relationship exists between sea anemone and clown fish. The clown fish protects the sea anemone from some of its predators, while the stinging cells of the anemone protect the clown fish; the fish also eats some of the detritus left behind when the anemone feeds. In commensalistic symbiotic relationships **(commensalism)**, one organism benefits while the other is neither helped nor hurt. One example of this type of relationship exists between trees and epiphytes (bromeliads and some orchids). The trees are not affected by the epiphytes growing in them, and the epiphytes benefit by collecting water running down the bark and get better access to light than they would on the ground. Finally, **parasitism** is a relationship in which one species is harmed and the other benefits; for example, the relationship that exists between fleas and dogs.

HOW ECOSYSTEMS CHANGE

Believe it or not, oftentimes the biotic balance in a community is maintained by a single species, known as the **keystone species.** A keystone species is a species whose very presence contributes to an ecosystem's diversity and whose extinction would consequently lead to the extinction of other forms of life. For example, fig trees are the keystone species in a tropical forest; likewise wolves were introduced back into Yellowstone Park because without wolves to control the number of herbivores, the ecosystem had drastically changed. As a general rule, if the keystone species is removed from an ecosystem, then the ecosystem completely changes.

Indicator species are species that are used as a standard to evaluate the health of an ecosystem. They are more sensitive to biological changes within their ecosystems than are other species, so they can be used as an early warning system to detect dangerous changes to a community. Trout are a common indicator species, because they are particularly sensitive to pollutants in water. The disappearance of trout from a particular habitat is a warning that that habitat is becoming polluted.

Indigenous species are those that originate and live or occur naturally in an area or environment. With increasing frequency, however, new species are being introduced into ecosystems by chance, by accident, or with intention. While some introduced species cannot find a niche and die out, many others are quite happy in their new environment, and compete successfully with the indigenous species. One example of this is grey squirrels, which were introduced to England in 1876. The grey squirrel competed with England's native species of squirrel, the red squirrel, and today there are fewer than 30,000 red squirrels alive in England. Another example of the harm that introduced species can do was seen when, in 1904, a fungus was introduced accidentally into the deciduous forests of the eastern United States; this fungus caused a blight that killed nearly all of the chestnut trees by the early 1950s.

Although some people don't like to use the term **invasive species** because they feel that it's derogatory, it is often used to describe introduced species. Two other examples of invasive species are zebra mussels, which were introduced into the Great Lakes when ships dumped ballast water into the lakes; and the quickly growing vine kudzu, which was originally introduced in the southeastern United States in order to control the problem of erosion.

Ecological Succession

Communities are not static; they are constantly changing. Species of plants and animals are continually coming and going; evolving and dying out. Some of the changes that take place in a geographic area are predictable ones that can be described as **ecological succession.**

If ecological succession begins in a virtually lifeless area, such as the area below a retreating glacier, it is called **primary succession. Secondary succession** is ecological succession that takes place where an existing community has been cleared (by events such as fire, tornado, or human impact), but the soil has been left intact. The organisms in the first stages of either type of succession are referred to as **pioneer species,** and typically have wide ranges of environmental tolerance. The communities in each stage of succession drive the environmental changes that will allow the next stage to take over. The final stage of succession, in which there is a dynamic balance between the abiotic and biotic components of the community, is referred to as the **climax community.**

How does a new habitat full of bare rocks eventually turn into a forest? The first stage of the job usually falls to a community of lichens. Lichens are hardy organisms. They can invade an area, land on bare rocks and erode the rock surface, and over time turn them into soil. Lichens are pioneer organisms. Once lichens have made an area more habitable, other organisms can settle in. Lichens are replaced (out-competed!) by mosses and ferns, which in turn are replaced by tough grasses, then low shrubs, then conifers, then short-lived hardwood trees such as dogwood and red maple trees, and finally long-lived hardwood trees. Below is a typical flowchart of ecological succession for a deciduous forest. Note that the stages are classified by the major new plant group, but remember that with the introduction of each new plant species comes an array of different animal species that prey upon it.

Ecological Succession

Bare rock

↓

Lichen, Algae, Mosses, Bacteria
(Break down rock and leave organic debris which together forms soil)

↓

Grasses
(Add organic matter to soil and anchor it in place)

↓

Small herbaceous plants
(Continue to add organic matter to soil)

↓

Small bushes
(Add shelter and shade for other plants)

↓

Conifers
(Create additional habitats)

↓

Short-lived hardwoods such as dogwood and red maple
(Can tolerate shade of conifers but are short-lived and vulnerable to damage)

↓

Long-lived hardwoods
(More specialized, hardier hardwoods such as oak and hickory)

We're almost done with this chapter, but you need to know a few more terms and concepts before you can move on to the population chapter. The following material will almost certainly be asked about on the test.

When the size of an organism's natural habitat is reduced, or when, for example, development occurs that isolates the habitat, this process is called **habitat fragmentation.** Habitat fragmentation can be quite damaging. As you know, ecosystems are not isolated; they abut each other and meet at wide and overlapping boundaries, called **ecotones.** At these boundaries, there is greater species diversity and biological density than there is in the heart of ecological communities, and this is called the **edge effect.** Some species can only live on the edge of certain habitats, and if the boundaries of a habitat are changed, a new edge is created, and both the edge and interior habitats are damaged.

The **theory of island biogeography** was first developed to address species diversity on actual islands, but has since been extended to apply to habitable areas that are surrounded by inhabitable areas. According to the theory, the number of species found on an undisturbed "island" is determined by two factors: immigration and extinction.

Whew. You're done with this chapter! Congratulations. Before moving on to the next chapter (Population Ecology), do the questions in the drill—and don't forget to use the techniques you learned in Chapter 2!

KEY TERMS

Make sure you know these words and how to use them in your essays!

Cycles in Nature

- reservoir
- exchange pool
- residency time
- Law of Conservation of Matter
- precipitation
- groundwater
- evaporation
- transpiration
- respiration
- photosynthesis
- nitrogen fixation
- nitrification
- assimilation
- ammonification
- denitrification
- phosphorus cycle
- sulfur cycle

Food Chains and Food Webs

- autotroph
- heterotroph
- producer
- consumers: primary, secondary, tertiary
- detrivore
- decomposer
- Net Primary Productivity
- trophic level
- food chain
- energy pyramid
- bioaccumulation
- biomagnification
- food web

Ecosystems

- biomes
- aquatic life zones
- ecotone
- ecozone
- deciduous trees
- coniferous trees

Evolution

- microevolution
- macroevolution
- population
- community
- niche
- habitat
- competition: intraspecific, interspecific
- Gause's principle
- realized niche, fundamental niche
- predation
- symbiotic relationship
- mutualism
- commensalism
- parasitism
- species
- natural selection
- gene pool
- genetic drift
- extinction
- evolutionary fitness

How Ecosystems Change

- keystone species
- indicator species
- indigenous species
- invasive species
- ecological succession
- primary succession
- secondary succession
- pioneer species
- climax community
- habitat fragmentation
- edge effect
- island biography theory

CHAPTER 4 QUIZ

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case.

1. The relationship between a tick and a bird is best described as which of the following?

   (A) Commensalism
   (B) Mutualism
   (C) Parasitism
   (D) Neutralism
   (E) Competition

2. When two species live in the same habitat and use exactly the same resources, which of the following will probably occur?

   (A) The two species can live together indefinitely.
   (B) One of the species will eventually die.
   (C) One species will evolve into a parasite.
   (D) The two species do not interact.
   (E) This competition does not occur in nature.

3. Organisms use different resources in the same habitat, and in this way avoid competition. This is referred to as

   (A) the Law of Tolerance
   (B) hunting and gathering
   (C) predator-prey relationship
   (D) resource partitioning
   (E) commensalism

4. Which of the following is true about the roles of both parasites and predators in ecosystems?

   (A) Predators and parasites can act as environmental resistance and allow the host population to grow.
   (B) Predators are generally smaller and parasites support many predators.
   (C) Predators generally have specialized means to capture prey.
   (D) Predators and parasites can divide the host population so that both can feed off the hosts.
   (E) Parasites and predators eliminate the weak and sick, leaving the strongest to reproduce.

5. All of the following are true concerning the characteristics of a climax community EXCEPT

   (A) the adult plants are small in size
   (B) there are many different species of plants
   (C) there is a mixture of decomposers, producers, and consumers
   (D) most of the organisms are specialists in their niche requirements
   (E) there is a large amount of biomass

6. Which of the following describes the direction of the flow of energy in a food chain?

   (A) From parasite to host
   (B) From predator to prey
   (C) From prey to predator
   (D) From one mutual to another
   (E) From prey to commensal

7. Which of the following element's cycles includes long-term storage in rocks and a short storage time in the atmosphere?

   (A) Sulfur
   (B) Carbon
   (C) Nitrogen
   (D) Calcium
   (E) Uranium

8. The current trend where some species of bacteria have become resilient to antibiotics is best described as

   (A) genetic diversity
   (B) speciation
   (C) extinction
   (D) macroevolution
   (E) microevolution

9. Large herds of grazing mammals are most likely to be located in a

   (A) rain forest
   (B) estuary
   (C) coniferous forest
   (D) grasslands
   (E) desert

Directions: Each set of lettered choices below refers to the numbered questions or statements immediately following it. Select the one lettered choice that best answers each question or best fits each statement. A choice may be used once, more than once, or not at all in each set.

Questions 10-14 refer to the process of succession.

(A) Inertia
(B) Disturbance
(C) Primary succession
(D) Secondary succession
(E) Tolerance

10. When late succession plants are not disturbed by early succession plants

11. When succession starts from an area where humans once farmed

12. When a community starts from bare rock

13. The tendency of an ecosystem to maintain its overall structure

14. An event that will instigate the process of succession

Questions 15-19 deal with types of species.

(A) specialist species
(B) keystone species
(C) native species
(D) alien species
(E) indicator species

15. The species that normally live and thrive in a habitat

16. Species that play a pivotal role in the habitat

17. A species whose decline indicates damage to the habitat

18. A nonnative species

19. A species with a narrow niche, which can only live in a certain habitat

Free-Response Question

1. Students from a local high school participated in a study of Hillside Pond. After safely taking samples of some small fish, a fish-eating hawk, some pond water, some zooplankton, and a fish that preys on the small fish, they determined the average concentration of compound "X" in each sample. The table below summarizes their data.

Organism	Compound "X" concentration
Small fish	0.1 ppm
Hawk	3.0 ppm
Pond water	0.1 ppb
Zooplankton	0.2 ppb
Predatory fish	1.0 ppm

(a) Describe one process that would cause compound "X" to contaminate the pond's water.

(b) Draw a food chain that illustrates the correct trophic order in the pond. Include the concentrations of compound "X" for each part of the chain.

(c) Describe a process that would explain the different concentrations of compound "X" in each organism.

(d) Describe one real-life example of a substance that behaves like compound "X" in the oceans. Give one negative effect that the substance might have on humans.

ANSWERS AND EXPLANATIONS

Multiple-Choice Answers

1. **C** The relationship between the bird and the tick is best described as parasitism, which is one type of symbiotic relationship. In this case, the parasite is the tick; it benefits from the relationship, while the bird is harmed.

2. **B** This concept is called competitive exclusion. The idea behind competitive exclusion is that two species that share the same niche cannot infinitely exist in the same ecosystem; eventually one will prove to be more fit and out-compete the other.

3. **D** Different species can use slightly different parts of the habitat to avoid direct competition with other species. For example, there are five species of warblers that can all live in the same pine tree. They can coexist because each species feeds in a different part of the tree: the trunk, at the ends of the branches, and at other sites.

4. **E** One aspect of the roles of both predators and parasites in an ecosystem is that they generally eliminate the weakest members of a population. The weakest individuals are those who are young, sick, or old; these individuals are eliminated, leaving the best-adapted organisms to survive and reproduce.

5. **A** (A) is false. Small adult plants are found in early succession stages. The other characteristics are all true of climax communities.

6. **C** Food chains show feeding relationships. The energy in a food chain flows from the Sun, through producers (plants), to primary consumers, to secondary consumers, and then to tertiary consumers. In other words, energy flows from prey to predator: choice (C).

7. **A** Sulfur is stored as sulfur salts in rocks and as sulfur dioxide in the atmosphere.

8. **E** Microevolution is the process where a population shows small scale genetic changes over a short period of time. Antibiotic resistance in bacteria occurs when overuse of antibiotics kills off the susceptible cells and the resistant ones are able to thrive.

9. **D** Grasslands can support large numbers of animals and the herd helps with protection from predators.

10. **E** When late succession plants are not disturbed by early succession plants, they are exhibiting tolerance.

11. **D** When succession starts from an area where humans once farmed, it's called secondary succession.

12. **C** When a community starts from bare rock, this process is called primary succession.

13. **A** The tendency of an ecosystem to maintain its overall structure is known as inertia.

14. **B** A disturbance is an event that will instigate the process of succession.

15. **C** Native species are those species that normally live and thrive in a particular habitat.

16. **B** Keystone species are species that play a pivotal role in the habitat.

17. **E** Indicator species are species whose decline indicates damage to a habitat.

18. D Alien species are not native to a particular environment; they have been introduced to the environment.

19. A A specialist species is one that has a narrow niche, and can only live in a certain habitat.

Free-Response Question

Key

(a) Compound X can enter the pond from surface water runoff that carries the compound. It could also enter the pond by being carried in by rain, snow, or dust that falls into the water. The substance might get carried in by ground water from a polluted aquifer. *(2 points maximum, one point for the correct name and one point for a correct description of the process)*

(b) Water (0.1 ppb) → Zooplankton (0.2 ppb) → Small fish (0.1 ppm) → Predatory fish (1.0 ppm) → Hawk (3.0 ppm) *(2 points maximum, 1 point for correct order and one point for the concentrations)*

(c) Bioaccumulation and biomagnification are two of the most important processes to know for the test. In bioaccumulation, fat-soluble molecules accumulate and stay in the fatty tissues of animals since they can not dissolve in water. Biomagnification occurs when compounds are passed from prey to predator. Since a predator needs to eat a lot of prey, each of the prey organisms gives some of the compound to the predator. The compounds accumulate and the concentration becomes much higher than you would expect to be in the environment. *(4 points maximum, 2 points for a correct description of each process)*

(d) Mercury and PCB's (polychlorinated biphenyl) are two very common molecules that bioaccumulated and biomagnify. For PCB's - skin conditions such as chloracne and rashes, changes in blood and urine that may indicate liver damage, dermal and ocular lesions, irregular menstrual cycles, lowered immune response, fatigue, headache, cough, and in children poor cognitive development. For mercury - itching, burning or pain, skin discoloration (pink cheeks, fingertips and toes), swelling, desquamation (shedding of skin), sweating, tachycardia, increased salivation, and hypertension. Affected children may show red cheeks, nose and lips, loss of hair, teeth, and nails, transient rashes, muscle weakness, and increased sensitivity to light. Other symptoms may include kidney disfunction, emotional lability, memory impairment, or insomnia. *(2 points maximum, 1 for the compound and 1 of a correct symptom associated with the compound).*