Chapter 9: Ecology
Lesson 9.4: Ecological Succession and Biogeochemical Cycles

Can a plant really grow in hardened lava? It can if it is very hardy and tenacious. And that is how succession starts. It begins with a plant that must be able to grow on new land with minimal soil or nutrients.

Lesson Objectives

- Outline primary and secondary succession, and define climax community.
- Define biogeochemical cycles.
- Describe the water cycle and its processes.
- Give an overview of the carbon cycle.
- Outline the steps of the nitrogen cycle.
- Understand the phosphorus cycle.
- Describe the ecological importance of the oxygen cycle.

Vocabulary

- biogeochemical cycle
- carbon cycle
- climax community
- condensation
- ecological succession
- evaporation
- groundwater
- nitrogen cycle
- nitrogen fixation
- phosphorus cycle
- pioneer species
- precipitation
- primary succession
- runoff
- secondary succession
- sublimation
- transpiration
- water cycle

Introduction

Communities are not usually static. The numbers and types of species that live in them generally change over time. This is called ecological succession. Important cases of succession are primary and secondary succession.

In Earth science, a biogeochemical cycle or substance turnover or cycling of substances is a pathway by which a chemical substance moves through both biotic (biosphere) and abiotic (lithosphere, atmosphere, and hydrosphere) compartments of Earth. A cycle is a series of change which comes back to the starting point and which can be repeated. Water, for example, is always recycled through the water cycle. The water undergoes evaporation, condensation, and precipitation, falling back to Earth. Elements, chemical compounds, and other forms of matter are passed from one organism to another and from one part of the biosphere to another through biogeochemical cycles.

The term "biogeochemical" tells us that biological, geological and chemical factors are all involved. The circulation of chemical nutrients like carbon, oxygen, nitrogen, phosphorus, calcium, and water etc. through the biological and physical world are known as biogeochemical cycles. In effect, the element is recycled, although in some cycles there may be places (called *reservoirs*) where the element is accumulated or held for a long period of time (such as an ocean or lake for water).

Ecological Succession

When you see an older forest, it's easy to picture that the forest has been there forever. This is not the case. Ecosystems are "dynamic." This means that ecosystems change over time. That forest may lie on land that was once covered by an ocean millions of years ago. Lightning may have sparked a fire in a forest, destroying much of the plant life there. Or the forest may have been cut down at one point for agricultural use, then abandoned and allowed to re-grow over time. During the ice ages, glaciers once covered areas that are tropical rainforests today. Both natural forces and human actions cause ecosystems to change.

If there is a big ecosystem change caused by natural forces or human actions, the plants and animals that live there may be destroyed. Or they may be forced to leave. Over time, a new community will develop, and then that community may be replaced by another. You may see several changes in the plant and animal composition of the community over time. Ecological succession is the constant replacement of one community by another. It happens after a big change in the ecosystem. And, of course, succession occurs on brand new land.

There are two main types of succession, primary and secondary:

Primary succession is the series of community changes which occur on an entirely new habitat which has never been colonized before. For example, a newly quarried rock face or sand dunes.

Secondary succession is the series of community changes which take place on a previously colonized, but disturbed or damaged habitat. For example, after felling trees in a woodland, land clearance or a fire.

Primary Succession

Primary succession is the type of ecological succession that happens on new lands—lands where life has not yet existed. Primary succession can take place after lava flow cools and hardens into new land, or a glacier recedes exposing new land, or when a landslide uncovers an area of bare rock. Since the land that results from these processes is completely new land, soil must first be produced. How is soil produced?

Primary succession always starts with a pioneer species**.** This is the species that first lives in the habitat. If life is to begin on barren rock, which is typical of new land, the pioneer species would be an organism such as a lichen (**Figure 9.31**). A lichen is actually an organism formed from two species. It results from a symbiotic relationship between a fungus and an algae or cyanobacteria. The lichen is able to thrive as both the fungus and the algae or bacteria contribute to the relationship. The fungus is able to absorb minerals and nutrients from the rock, while algae supplies the fungus with sugars through photosynthesis. Since lichens can photosynthesize and do not rely on soil, they can live in environments where other organisms cannot. As a lichen grows, it breaks down the rock, which is the first step of soil formation.

Figure 9.31: Primary succession on a rock often begins with the growth of lichens.

The pioneer species is soon replaced by other populations. Abiotic factors such as soil quality, water, and climate will determine the species that continue the process of succession. Mosses and grasses will be able to grow in the newly created soil. During early succession, plant species like grasses that grow and reproduce quickly will take over the landscape. Over time, these plants improve the soil and a few shrubs can begin to grow. Slowly, the shrubs are replaced by small trees. Small trees then are succeeded by larger trees. Since trees are more successful at competing for resources than shrubs and grasses, a forest may be the end result of primary succession.

Secondary Succession

Sometimes ecological succession occurs in areas where life has already existed. These areas already have soil full of nutrients. Secondary succession is the type of succession that happens after something destroys the habitat, such as a flood or other natural disaster. Abandoning a field that was once used for agriculture can also lead to secondary succession (**Figure 9.32**). In this case, the pioneer species would be the grasses that first appear. Lichen would not be necessary as there is already nutrient-rich soil. Slowly, the field would return to its natural state.

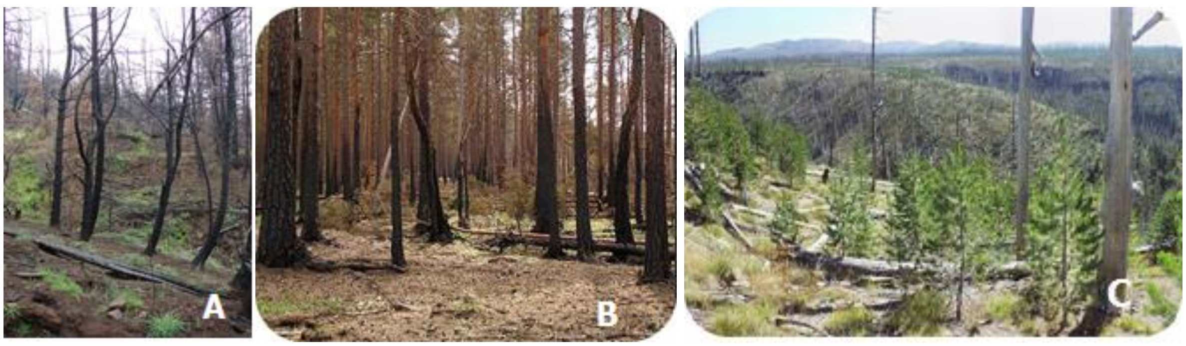

Figure 9.32: Secondary succession: (A) This land was once used for growing crops. Now that the field is abandoned, secondary succession has begun. Pioneer species, such as grasses, appear first, and then shrubs begin to grow. (B) The early stages of succession after a forest fire are shown in these pictures. Taken four years after the fire, they show the charred remains of the original forest as well as the small grasses and shrubs that are beginning to grow back in the area.(C) In 1988, a forest fire destroyed much of Yellowstone National Park. This photo, taken 17 years later, shows that the forest is gradually growing back. Small grasses first grew here and are now being replaced by small trees and shrubs. This is an example of the later stages of secondary succession.

A forest fire can alter a habitat such that secondary succession occurs (**Figure 9.32**). Although the area will look devastated at first, the seeds of new plants are underground. They are waiting for their chance to grow. Just like primary succession, the burned forest will go through a series of communities, starting with small grasses, then shrubs, and finally bigger trees.

Climax Communities

Many early ecologists thought that a community always goes through the same series of stages during succession. They also assumed that succession always ends with a final stable stage. They called this stage the climax community. Today, most ecologists no longer hold these views. They believe that continued change is normal in most ecosystems. They think that most communities are disturbed too often to become climax communities.

A climax community (**Figure 9.33**) is the end result of ecological succession. The climax community is a stable balance of all organisms in an ecosystem, and will remain stable unless a disaster strikes. After the disaster, succession will start all over again. Depending on the climate of the area, the climax community will look different. In the tropics, the climax community might be a tropical rainforest. At the other extreme, in northern parts of the world, the climax community might be a coniferous forest. Though climax communities are stable, are they truly the final community of the habitat? Or is it likely that sometime in the future, maybe a long time in the future, the community of populations will change, and another stable, climax community will thrive?

Figure 9.33: Climax Community, the trees are full grown and the ground is covered by underbrush.

Biogeochemical Cycles

The chemical elements and water that are needed by organisms continuously recycle in ecosystems. They pass through biotic and abiotic components of the biosphere. That's why their cycles are called biogeochemical cycles. For example, a chemical might move from organisms (*bio*) to the atmosphere or ocean (*geo*) and back to organisms again. Elements or water may be held for various periods of time in different parts of a cycle.

- Part of a cycle that holds an element or water for a short period of time is called an exchange pool. For example, the atmosphere is an exchange pool for water. It usually holds water (in the form of water vapor) for just a few days.
- Part of a cycle that holds an element or water for a long period of time is called a reservoir. The ocean is a reservoir for water. The deep ocean may hold water for thousands of years.

The rest of this lesson describes five biogeochemical cycles: the water cycle, carbon cycle, nitrogen, phosphorus cycle, and oxygen cycle.

The Water Cycle

Water on Earth is billions of years old. However, individual water molecules keep moving through the water cycle. The water cycle is a global cycle. It takes place on, above, and below Earth's surface, as shown in **Figure 9.34**.

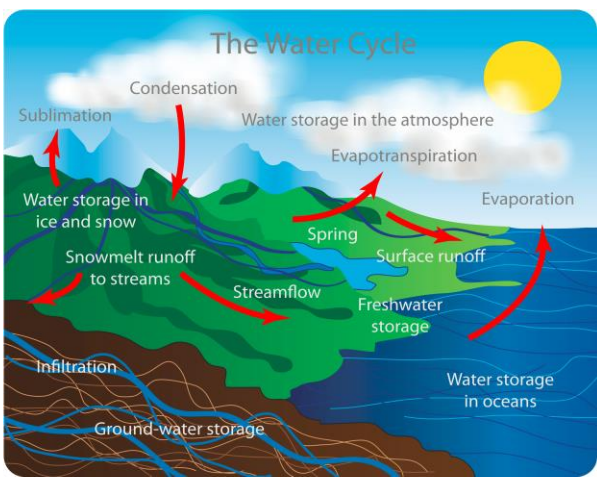

Figure 9.34: Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating.

During the water cycle, water occurs in three different states: gas (water vapor), liquid (water), and solid (ice). Many processes are involved as water changes state in the water cycle.

Evaporation, Sublimation, and Transpiration

Water changes to a gas by three different processes:

1. Evaporation occurs when water on the surface changes to water vapor. The sun heats the water and gives water molecules enough energy to escape into the atmosphere.
2. Sublimation occurs when ice and snow change directly to water vapor. This also happens because of heat from the sun.
3. Transpiration occurs when plants release water vapor through leaf pores called stomata (see **Figure 9.35**). The water is a product of photosynthesis.

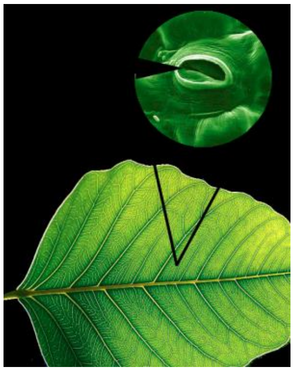

Figure 9.35: Plant leaves have many tiny stomata. They release water vapor into the air.

Condensation and Precipitation

Rising air currents carry water vapor into the atmosphere. As the water vapor rises in the atmosphere, it cools and condenses. Condensation is the process in which water vapor changes to tiny droplets of liquid water. The water droplets may form clouds. If the droplets get big enough, they fall as precipitation—rain, snow, sleet, hail, or freezing rain. Most precipitation falls into the ocean. Eventually, this water evaporates again and repeats the water cycle. Some frozen precipitation becomes part of ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or longer.

Groundwater and Runoff

Precipitation that falls on land may flow over the surface of the ground. This water is called runoff. It may eventually flow into a body of water. Some precipitation that falls on land may soak into the ground, becoming groundwater. Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater may be taken up by plant roots. Some may flow deeper underground to an aquifer. This is an underground layer of rock that stores water, sometimes for thousands of years.

The water cycle is demonstrated at:
http://www.youtube.com/watch?v=iohKd5FWZOE&feature=related.
The *Water Cycle Jump* can be viewed at http://www.youtube.com/watch?v=BayExatv8lE.

Tracking Raindrops

We all rely on the water cycle, but how does it actually work? Scientists at University of California Berkeley are embarking on a new project to understand how global warming is affecting our fresh water supply. And they're doing it by tracking individual raindrops in Mendocino and north of Lake Tahoe.

See http://www.kqed.org/quest/television/tracking-raindrops for more information.

The Carbon Cycle

Flowing water can slowly dissolve carbon in sedimentary rock. Most of this carbon ends up in the ocean. The deep ocean can store carbon for thousands of years or more. Sedimentary rock and the ocean are major reservoirs of stored carbon. Carbon is also stored for varying lengths of time in the atmosphere, in living organisms, and as fossil fuel deposits. These are all parts of the carbon cycle, which is shown in **Figure 9.36.**

The carbon cycle is discussed in the following video: http://www.youtube.com/watch?v=0Vwa6qtEih8.

Carbon cycles quickly between organisms and the atmosphere. Cellular respiration releases carbon into the atmosphere as carbon dioxide. Photosynthesis removes carbon dioxide from the atmosphere and uses it to make organic compounds. Carbon cycles far more slowly through geological processes such as sedimentation. Carbon may be stored in sedimentary rock for millions of years.

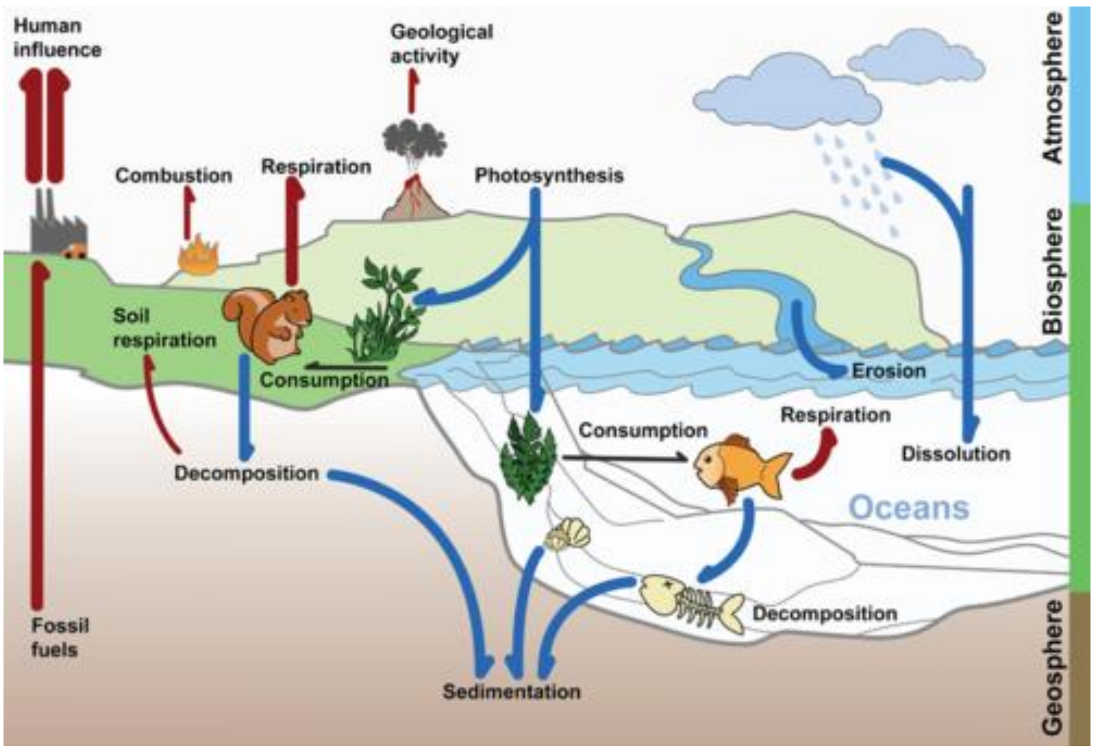

Figure 9.36: The Carbon Cycle. Carbon moves from one reservoir to another in the carbon cycle. What role do organisms play in this cycle?

Why is recycling carbon important? Recall that carbon is the cornerstone of organic compounds, the compounds necessary for life. But do organisms make their own carbon? Do they have the genes that encode proteins necessary to make carbon? No. In fact, there are no such genes. Carbon must be recycled from other living organisms, from carbon in the atmosphere, and from carbon in other parts of the biosphere.

Carbon in the Atmosphere

Though carbon can be found in ocean water, rocks and sediment and other parts of the biosphere, the atmosphere may be the most recognizable reservoir of carbon. Carbon occurs in various forms in different parts of the carbon cycle. Some of the different forms in which carbon appears are described in **Table 9.5** on the next page.

KEY: C = Carbon, O = Oxygen, H = Hydrogen

Table 9.5 Different forms of carbon and where they can be found.

Form of Carbon	Chemical Formula	**State**	**Main Reservoir**
Carbon Dioxide	CO_2	Gas	Atmosphere
Carbonic Acid	H_2CO_3	Liquid	Ocean
Bicarbonate Ion	HCO_3^-	Liquid(dissolved ion)	Ocean
Organic Compounds	*Examples:* $C_6H_{12}O_6$ (Glucose), CH_4(Methane)	Solid Gas	Biosphere Organic Sediments (Fossil Fuels)
Other Carbon Compounds	*Examples:* $CaCO_3$ (Calcium Carbonate), $CaMg(CO_3)_2$ (Calcium Magnesium Carbonate)	Solid Solid	Sedimentary Rock, Shells, Sedimentary Rock

Carbon in Carbon Dioxide

Carbon cycles quickly between organisms and the atmosphere. In the atmosphere, carbon exists primarily as carbon dioxide (CO_2). Carbon dioxide cycles through the atmosphere by several different processes, including those listed below.

- Living organisms release carbon dioxide as a byproduct of cellular respiration.
- Photosynthesis removes carbon dioxide from the atmosphere and uses it to make organic compounds.
- Carbon dioxide is given off when dead organisms and other organic materials decompose.
- Burning organic material, such as fossil fuels, releases carbon dioxide.
- Carbon cycles far more slowly through geological processes such as sedimentation. Carbon may be stored in sedimentary rock for millions of years.
- When volcanoes erupt, they give off carbon dioxide that is stored in the mantle.
- Carbon dioxide is released when limestone is heated during the production of cement.
- Ocean water releases dissolved carbon dioxide into the atmosphere when water temperature rises.
- Carbon dioxide is also removed when ocean water cools and dissolves more carbon dioxide from the air.

Because of human activities, there is more carbon dioxide in the atmosphere today than in the past hundreds of thousands of years. Burning fossil fuels and has released great quantities of carbon dioxide into the atmosphere. Cutting forests and clearing land has also increased carbon dioxide into the atmosphere because these activities reduce the number of autotrophic organisms that use up carbon dioxide in photosynthesis. In addition, clearing often involves burning, which releases carbon dioxide that was previously stored in autotrophs.

The Nitrogen Cycle

Nitrogen makes up 78 percent of Earth's atmosphere. It's also an important part of living things. Nitrogen is found in proteins, nucleic acids, and chlorophyll. The nitrogen cycle moves nitrogen through the abiotic and biotic parts of ecosystems. **Figure 9.37** shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes through a similar cycle in aquatic ecosystems.

Plants cannot use nitrogen gas from the air to make organic compounds for themselves and other organisms. The nitrogen gas must be changed to a form called nitrates, which plants can absorb through their roots. The process of changing nitrogen gas to nitrates is called nitrogen fixation. It is carried out by nitrogen-fixing bacteria. The bacteria live in soil and roots of legumes, such as peas.

When plants and other organisms die, decomposers break down their remains. In the process, they release nitrogen in the form of ammonium ions. Nitrifying bacteria change the ammonium ions into nitrates. Some of the nitrates are used by plants. Some are changed back to nitrogen gas by denitrifying bacteria.

The nitrogen cycle is discussed at http://www.youtube.com/watch?v=pdY4I-EaqJA&feature=fvw.

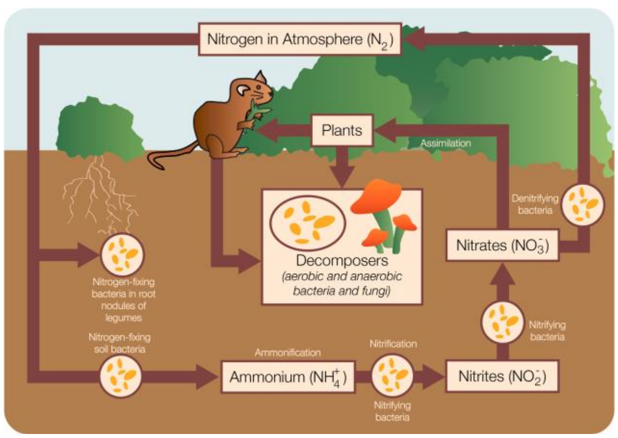

Figure 9.37: Nitrogen cycles between the atmosphere and living things.

Phosphorus Cycle

The phosphorus cycle is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere, see **Figure 9.38**. The phosphorus cycle differs from the other major biogeochemical cycles in that it does not include a gas phase; although small amounts of phosphoric acid (H_3PO_4) may make their way into the atmosphere, contributing ? in some cases ? to acid rain. The water, carbon, nitrogen and sulfur cycles all include at least one phase in which the element is in its gaseous state. Very little phosphorus circulates in the atmosphere because at Earth's normal temperatures and pressures, phosphorus and its various compounds are not gases. The largest reservoir of phosphorus is in sedimentary rock.

It is in these rocks where the phosphorus cycle begins. When it rains, phosphates are removed from the rocks (via weathering) and are distributed throughout both soils and water. Plants take up the phosphate ions from the soil. The phosphates then moves from plants to animals when herbivores eat plants and carnivores eat plants or herbivores. The phosphates absorbed by animal tissue through consumption eventually returns to the soil through the excretion of urine and feces, as well as from the final decomposition of plants and animals after death.

The primary biological importance of phosphates is as a component of nucleotides, which serve as energy storage within cells (ATP) or when linked together, form the nucleic acids DNA and RNA. The double helix of our DNA is only possible because of the phosphate ester bridge that binds the helix. Phosphorus is also found in bones, whose strength is derived from calcium phosphate in enamel of mammalian teeth; exoskeleton of insects and phospholipids (found in all biological membranes) and it also functions as buffering agent in maintaining acid base homeostasis in the human body.

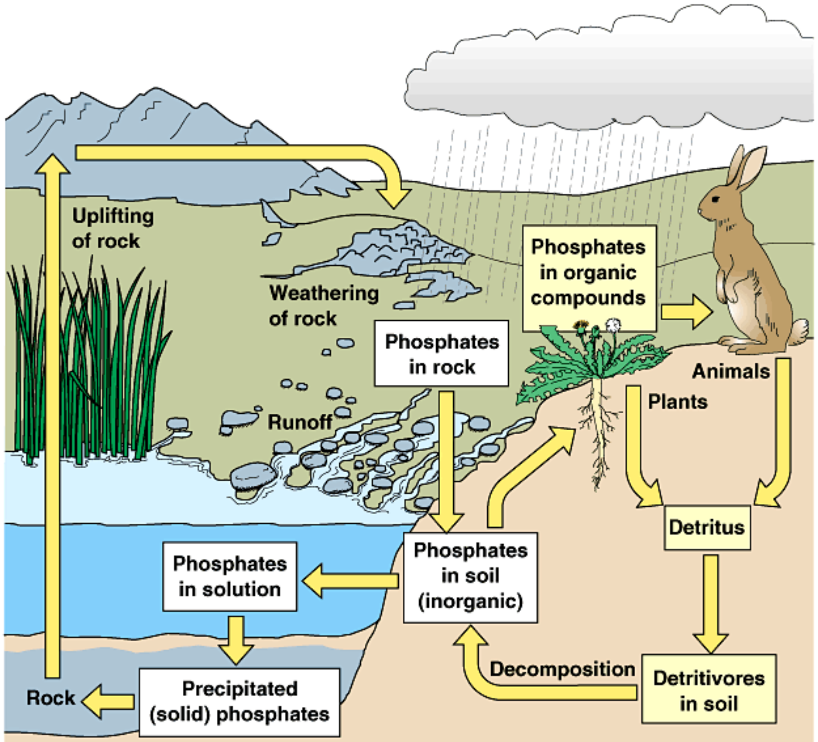

Figure 9.38: The Phosphorous Cycle shows how phosphorous is recycled in ecosystems.

The Oxygen Cycle

The oxygen cycle is the biogeochemical cycle that describes the movement of oxygen within its three main reservoirs: the atmosphere (air), the total content of biological matter within the biosphere, and the lithosphere (Earth's crust), see **Figure 9.39** on the next page. The main driving factor of the oxygen cycle is photosynthesis, which is responsible for the modern Earth's atmosphere and life on earth.

By far the largest reservoir of Earth's oxygen is within the silicate and oxide minerals of the crust and mantle (99.5%). Only a small portion has been released as free oxygen to the biosphere (0.01%) and atmosphere (0.36%). The main source of atmospheric free oxygen is photosynthesis, which produces sugars and free oxygen from carbon dioxide and water.

Photosynthesizing organisms include the plant life of the land areas as well as the phytoplankton of the oceans. The tiny marine cyanobacteria Prochlorococcus was discovered in 1986 and accounts for more than half of the photosynthesis of the open ocean. An additional source of atmospheric free oxygen comes from photolysis, whereby high energy ultraviolet radiation breaks down atmospheric water and nitrous oxide into component atoms. The free H and N atoms escape into space leaving O_2 in the atmosphere.

The main way free oxygen is lost from the atmosphere is via respiration and decay, mechanisms in which animal life and bacteria consume oxygen and release carbon dioxide. The lithosphere also consumes free oxygen via chemical weathering and surface reactions. An example of surface weathering chemistry is formation of iron-oxides (rust):

Oxygen is also cycled between the biosphere and lithosphere. Marine organisms in the biosphere create calcium carbonate shell material ($CaCO_3$) that is rich in oxygen. When the organism dies its shell is deposited on the shallow sea floor and buried over time to create the limestone sedimentary rock of the lithosphere. Weathering processes initiated by organisms can also free oxygen from the lithosphere. Plants and animals extract nutrient minerals from rocks and release oxygen in the process.

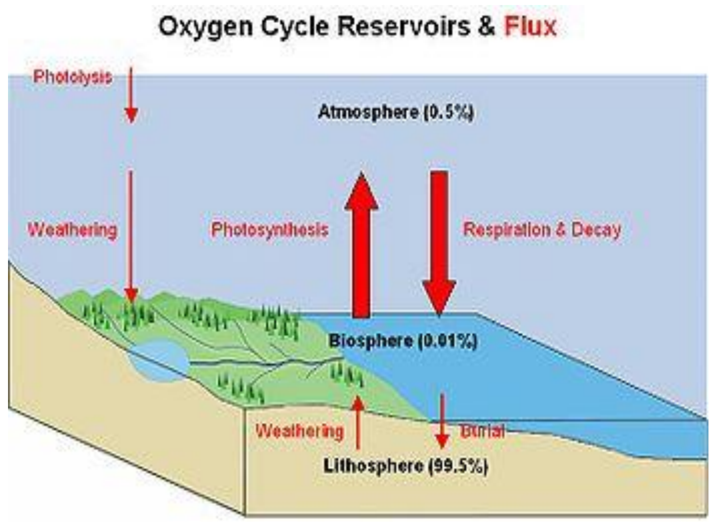

Figure 9.39 The Oxygen Cycle shows how oxygen is released and returned in ecosystems.

Lesson Summary

- Ecological succession is the constant replacement of one community by another.
- Primary succession occurs in an area that has never before been colonized by plants and animals, while secondary succession occurs in an established area that was disturbed.
- Secondary succession is the type of succession that happens after something destroys the habitat, such as a flood or other natural disaster.
- Climax communities is the end result of ecological succession.
- Chemical elements and water are recycled through biogeochemical cycles. The cycles include both biotic and abiotic parts of ecosystems.
- The water cycle takes place on, above, and below Earth's surface. In the cycle, water occurs as water vapor, liquid water, and ice. Many processes are involved as water changes state in the cycle. The atmosphere is an exchange pool for water. Ice masses, aquifers, and the deep ocean are water reservoirs.
- In the carbon cycle, carbon passes among sedimentary rocks, fossil fuel deposits, the ocean, the atmosphere, and living things. Carbon cycles quickly between organisms and the atmosphere. It cycles far more slowly through geological processes.
- The nitrogen cycle moves nitrogen back and forth between the atmosphere and organisms. Bacteria change nitrogen gas from the atmosphere to nitrogen compounds that plants can absorb. Other bacteria change nitrogen compounds back to nitrogen gas, which re-enters the atmosphere.
- The phosphorous cycle moves from inorganic sources such as rock and soil to water to terrestrial and aquatic organisms. Unlike the other biogeochemical cycles, phosphorous does not exist in the atmosphere as a gas.
- In the oxygen cycle, oxygen is recycled between the atmosphere, biosphere, and lithosphere. While 99.5% of oxygen is tied up in silicate and oxide minerals and unavailable to organisms, the primary source of oxygen in the atmosphere is photosynthesis. Respiration and decomposition in organisms removes oxygen from the atmosphere.

References/ Multimedia Resources

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