High School Biology

Science course from Educational Options

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Lesson 4: Energy Flow and Nutrient Cycling

Objectives

By the end of this lesson, students will be able to:

- compare and contrast food chains and food webs
- explain the concept of biomagnification
- diagram and analyze ecological pyramids
- describe the different biogeochemical cycles that take place in ecosystems
- explain how carbon dioxide emissions are related to global warming

Click here for the course glossary

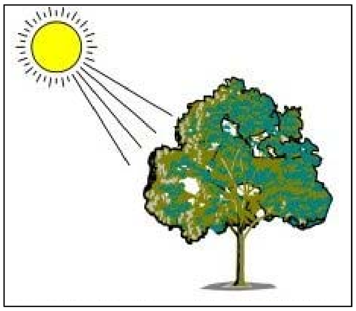
Introduction

The previous lesson covered the dynamics of population and community ecology. This lesson explores interactions that occur within an ecosystem. Recall that an ecosystem consists of an area's **abiotic** and **biotic** components.

The first sections of this lesson focus on energy and matter. This will deepen your understanding of the interactions within an ecosystem. In ecosystems, energy flows in one direction. Matter cycles through an ecosystem. Both energy flow and matter cycling are related to the feeding relationships within ecosystems.

Trophic Structure in Ecosystems

Growth, survival, and reproduction require energy. How do you obtain energy? You eat. Organisms in nature must also obtain energy to perform daily functions. They do so by either taking in food or making it themselves.



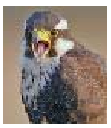
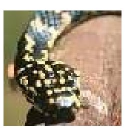
Energy enters most ecosystems in the form of sunlight. Photosynthetic organisms use sunlight to make food. These organisms are then consumed by other organisms, which are fed on by other organisms, and so on. An ecosystem's feeding system is its **trophic structure**. The term trophic refers to "feeding." Trophic structures help explain why certain organisms compete for food.

Food Chains

A **food chain** shows a single path of feeding and energy flow within an ecosystem. Every organism within a food chain has a function. Its location in the food chain reflects its function. The diagram below is an example of a terrestrial food chain. Below each picture is a description of the organism. The description includes the type of food it makes or consumes. The **trophic level** is the organism's position in the food chain. Notice that this food chain contains arrows. The top of the arrow points toward the organism that consumes (eats) the organism below it. This also represents energy flow through the food chain. Each organism consumes energy. It uses some of it and passes the rest along to be consumed by another organism. The food chain's length is limited as less and less energy is passes from one level to the next.

Not all food chains are the same length. They vary from ecosystem to ecosystem. Some food chains only go up to secondary or **tertiary** consumers. The size of the ecosystem often determines the length of the food chain. In a large lake, there are more links between top predators and organisms at the bottom of the food chain.

Examine the following food chain. Start at the bottom and work your way to the top.

	Trophic Level	
	Quaternary consumers	This is the top of the food chain. This level includes the quaternary consumers, or the fourth level of consumers. They are carnivores because they consume other animals. Top level carnivores include sharks, bobcats, and polar bears.
carnivore		
↑		
	Tertiary consumers	This level includes the tertiary consumers, or the third level of consumers. Since they consume other animals, they are also carnivores.
carnivore		
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	Secondary consumers	These organisms are consumers as well. They feed on other organisms. They are called secondary consumers. This is because they are the second level of consumers on this food chain. These animals are also **carnivores** because they only eat other animals. Examples of

carnivores include field mice and spiders.

carnivore

↑

Primary consumers

Herbivores are organisms that only consume autotrophs. They are **consumers** because they get their energy by feeding on other organisms. Herbivores are primary consumers because they are the first level of consumers above the autotroph. Examples of herbivores include grasshoppers and deer.

herbivore

↑

Primary producers

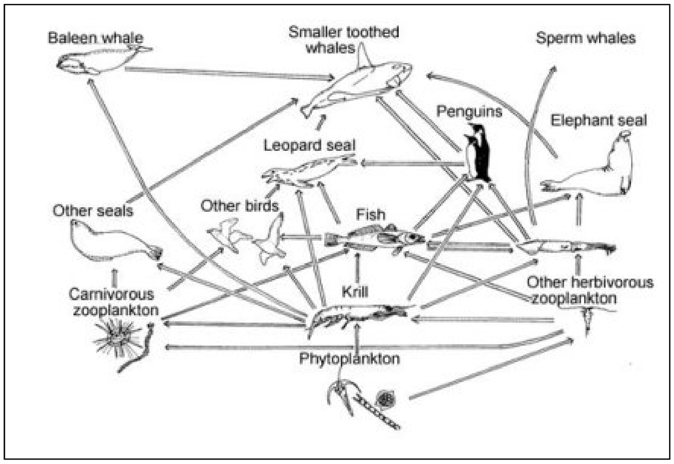
This is the bottom of a food chain. **Autotrophs**, or **primary producers**, trap solar energy through photosynthesis and convert it to sugar (food). Producers include plants, algae, and some bacteria.

autotroph

Decomposers are recyclers. They are found throughout the food chain. They break down animal waste, dead plants and animals. The result is the release of chemical nutrients back into the ecosystem. These chemical nutrients can be released in the air, soil, or water. Organisms then use these nutrients as fuel. Without decomposers, plants would not get the essential nutrients they need to survive. Decomposers also prevent dead matter and waste from piling up. Some decomposers, like fungi, can be seen with the naked eye. Others, like bacteria, are microscopic.

Food Webs

Food chains are relatively simple. They follow a single path. **Food webs**, on the other hand, are more complex. A food web is a series of interlocking food chains. An organism can have more than one function in a food web. An animal, for example, can be both a primary and a secondary consumer in a food web. In food webs, a single organism is either eaten by or eats several organisms.



The energy is passed around a food web in an unending circle of production and consumption. The removal of one organism from the chain affects all others in some way.

Examine the image of the arctic food web. Notice that there are arrows showing the direction of energy flow. Put simply, these arrows indicate what eats what. Just as in a food chain, the arrows point to the organism that consumes the organism at the end of the arrow. Look at the bottom of the food web. Notice that the **phytoplankton** are the primary producers. These are microscopic plants found in the ocean. Look at the organisms at the top of the food web. Two species of whales are the top predators.

Keystone Species

An ecosystem usually depends upon certain species within its food chain for balance. These **keystone species** substantially influence ecosystems' structures. The removal of a keystone species would drastically affect other organisms within the ecosystem.

One keystone species is the sea otter. Normally, these animals feed on sea urchins. These sea urchins then consume kelp, a type of seaweed. A balance is maintained when the sea otter population is normal. Examine the food chain below. If the sea otter population were to diminish, the sea urchins would reproduce uncontrollably. The large sea urchin population would then consume more of the ecosystem's kelp. They could then reduce the available kelp to the point that there is not enough for all of them to eat. Clearly, the removal of sea otters substantially disrupts the food chain.


sea otter

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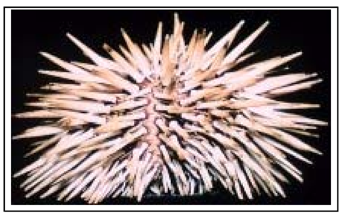
sea urchin

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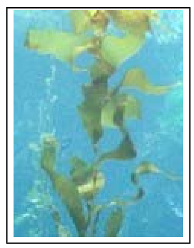

kelp

Real Life Scientist


Photo credit: Washington Post

Sharks are known to be the top predators of the ocean. They are also targeted by humans for sport or commercial goods. As a result, the shark population has dramatically declined. Researchers believe that sharks play a pivotal role in maintaining biodiversity in marine ecosystems. The depletion of sharks has had a devastating impact on the structure of the marine ecosystem. When sharks die off, the fish they eat increase in numbers. These fish then feed on parrotfish, which eat the algae on coral reefs. A lower parrotfish population harms the dynamics of the coral reef community.

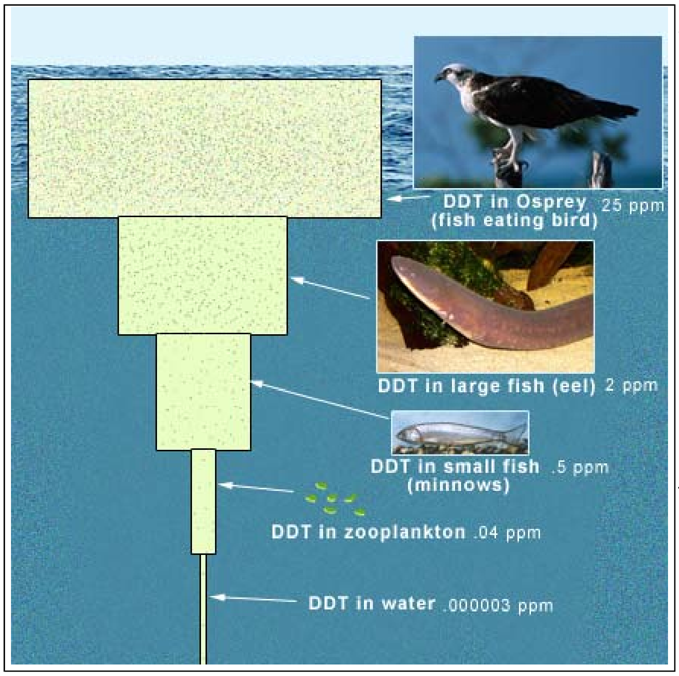
Dr. Ellen Pikitch, a marine scientist, studies the population and management of fisheries. Her research focuses on the population status and preservation of Caribbean sharks. In 2000, Dr. Pikitch launched the Glover Reef Shark Survey in Belize. This is a five year study on Caribbean sharks. Prior to this survey, little information pertaining to the population of sharks existed. The purpose of this project was to gain an understanding of the shark populations and to create a plan to preserve the sharks. Through a tracking device, Dr. Pikitch, along with her colleagues, discovered favorable migration patterns. This would allow the shark population to grow. Although the five year study has ended, she continues to observe the population dynamics of Caribbean sharks.

Biomagnification

Chemicals can also affect food chains and webs. Chemicals in an ecosystem either occur naturally or are introduced by humans. The chemicals of greatest concern are those that are considered to be pollutants. Pollutants include chemicals like mercury or those found in **pesticides** and **insecticides**. Such chemicals can harm the organisms in an ecosystem.

Recall that organisms consume one another in food chains and webs. Imagine that an organism at the bottom of the food chain (a plant) has a chemical on it, such as a pesticide. The organism above it on the food chain (say, a rabbit) eats that plant. The chemical pesticide will be passed from the plant to the rabbit. As chemicals are passed from one trophic level to the next, the chemical concentration (the strength) within organisms increases. As a result, the higher level organisms in the food chain will contain more chemicals than those below them. This is called **biomagnification**.

The diagram below shows the biomagnification of DDT in an ocean. DDT is a chemical that used to be used to kill insects. Humans would kill certain disease-carrying insects to protect themselves from infection. DDT can negatively affect organisms on land and in aquatic ecosystems.



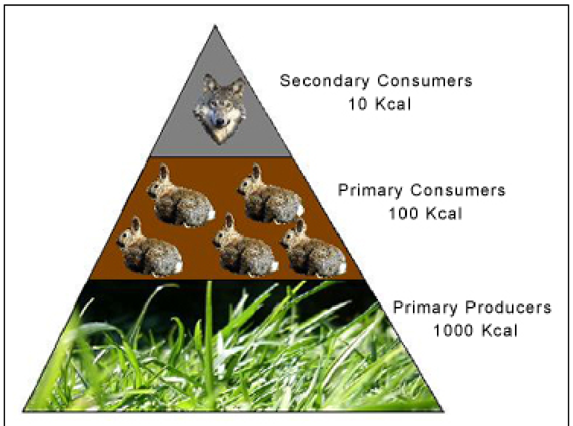
DDT can cause the following problems:

- It can slow growth and photosynthesis in some plants.
- Reproductive and nervous system disorders can occur in some organisms.
- In birds it can make egg shells thinner.
- In humans it can cause headaches, vomiting, and tremors.

The amount of DDT in each level of the food chain is shown as "ppm," which stands for "parts per million." Notice that this number increases as you move up the food chain.

Ecological Pyramids

Food chains do not stop at showing what eats what. They can also indicate the amount of energy passed from one organism to another. This information can be used to estimate the number of individuals at each level of the food chain.



Kilocalorie (Kcal) is a measurement of energy.

Pyramid of Energy

This image is an **energy pyramid**. The organisms are placed by trophic structure, much like you would see in a food chain. Notice, however, that this image is pyramid shaped. This shape demonstrates the amount of energy at each level of the food chain. Notice that the primary producers, the plants, have the most amount of energy. They obtain energy directly from sunlight. As you move up the pyramid, energy diminishes. Energy is lost between every level of a food chain. Only 10% of the energy at any given level is available for organisms at the next level.

Pyramid of Numbers

A **pyramid of numbers** represents the number of individuals at each trophic level of a food chain on a graph. Examine the image of the pyramid again. Most food chains usually have a large number of primary producers at the base. As you move up the food chain, there are fewer and fewer individual organisms at each trophic level. This is due to the way energy flows through the food chain. The amount of food going through the food chain decreases as it moves up the chain. Notice that the top predator, the wolf, has the least number of individuals. Populations of top predators, such as wolves, are usually small.

Think About It

What did you eat for your last meal? Did the meal include vegetables and meat? Where on a food chain do you think the food that you ate is located?

Biogeochemical Cycles in Ecosystems

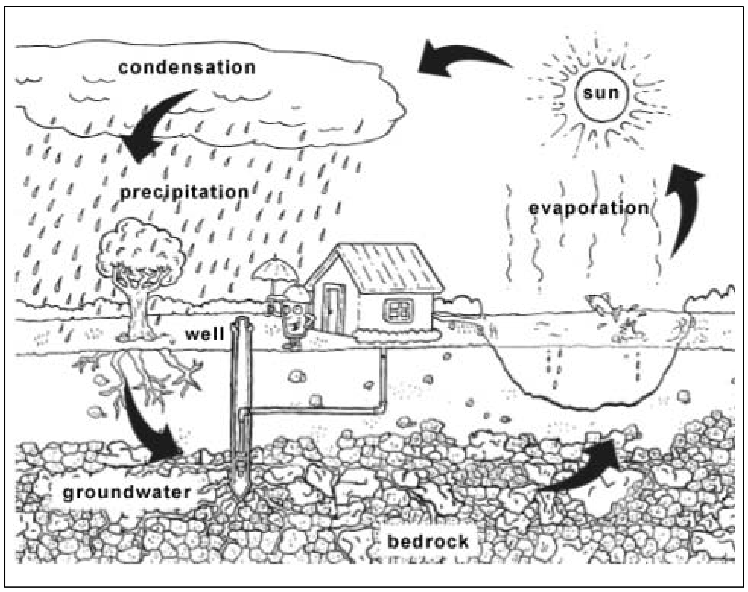
Energy is not the only thing that organisms need. They also need elements such as carbon, oxygen, and nitrogen. Molecules of various substances, like water, are also important. These elements and molecules exist in an ecosystem. They are constantly being recycled. This recycling of matter ensures that there is enough to go around for organisms' survival.

The cycling of matter between organisms and the environment is called **biogeochemical cycling**. "Bio" means life. "Geo" refers to the non-living parts of the Earth, such as rocks and minerals. "Chemical" refers to molecules, elements, and atoms. This part of the lesson will describe the way elements and molecules important to living things are used and recycled.

Water Cycle

Water is all around us. It is in oceans, lakes, snow, ponds, animals, and plants. Without water, life would not exist. Water has a unique property, in that it can exist in three different states: as a solid, liquid, or a gas. This enables it to cycle from the Earth's surface to the atmosphere and back to the surface again. The Earth has a limited amount of water. The cycling of water makes it possible for all living things to obtain enough for survival.

Examine the diagram of the water cycle. Notice the three forms that water takes in this cycle: precipitation, condensation, and evaporation.



Evaporation

Water has the ability to change from a liquid to a gas. This process is called **evaporation**. The heat from the sun causes this change to occur. Liquid water that undergoes evaporation turns to vapor or steam. The vapor or steam then goes up into the atmosphere. Evaporation occurs on the surface of rivers, lakes, oceans, and other bodies of water. Evaporation can take place on plants as well. Plants take in water through their roots. At times, some of this water is released from their leaves.

Condensation

What happens after water becomes a gas? The vapor form of water travels to the atmosphere. If the air gets cold enough, the vapor will then change back into a liquid and form a cloud. The process of water vapor turning into liquid is called **condensation**. Have you ever poured yourself a glass of cold tea on a warm summer day? If so, you may have noticed condensation on the glass. Condensation takes place high up in the clouds. Condensation can also take place closer to the Earth's surface.

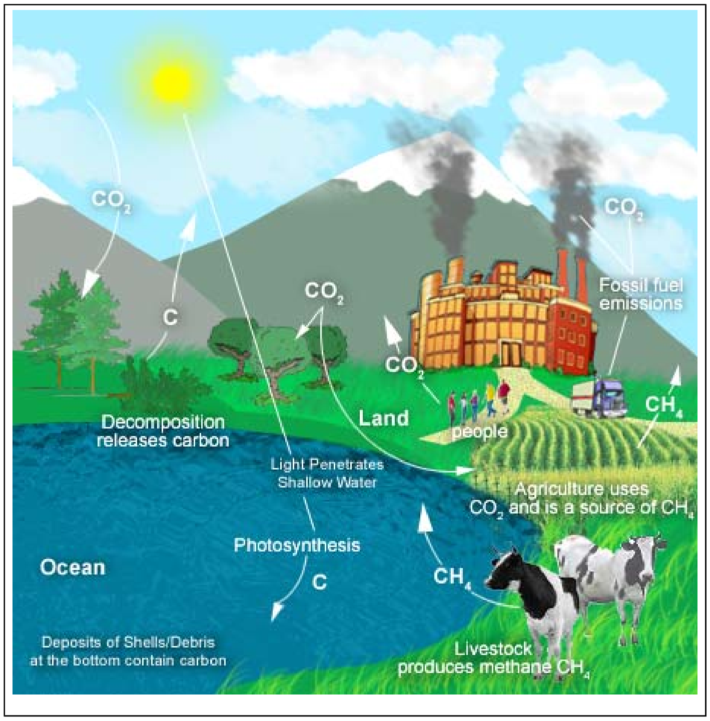
Precipitation

Whether you live in a warm climate or a cold one, you have probably seen some form of **precipitation**. Precipitation includes snow, rain, hail, or sleet. Clouds grow heavier as condensation takes place in the atmosphere. Eventually, the drops within the clouds fall back to the Earth's surface in the form of precipitation.

Precipitation that falls back to the Earth's surface can end up in many places. It can flow into bodies of water. Precipitation can also end up in the soil, thereby entering the groundwater supply.

Carbon Cycle

Carbon is an element that is found in every living thing. This element is also found all around us. It is present in the atmosphere as carbon dioxide (CO_2). Carbon is part of soil, it is dissolved in water, and it is also a component of rocks and trees. Look at the diagram of the carbon cycle. The arrows indicate the carbon's path.



Much like water, carbon is recycled so that organisms can use it over again. If it was not for recycling, carbon levels would be depleted. Therefore, carbon recycling is important for the survival of all organisms.

Plants take up CO_2 when they photosynthesize. The diagram shows this with trees on land. (Keep in mind, however, that this process takes place in all plants.) During a process called respiration, plants release CO_2 into the environment. The diagram indicates this process in the water plants (although, again, it takes place in all plants).

When plants die, they decompose and become part of the soil. Decomposers release carbon dioxide into the atmosphere when they break down dead plant and animal matter.

Animals and plants on farms also contribute to the carbon cycle. When animals eat plants, such as when a cow eats grass, they take in carbon from the plant. Their body then produces methane (CH_4), which contains carbon. This gas is then released into the atmosphere.

Organisms in the ocean also contribute to the carbon cycle. Photosynthesis and respiration take place in plants that live near the surface of the water. Some ocean-dwelling organisms have shells that are made up of carbon. Their predators take in this carbon when they feed on them.

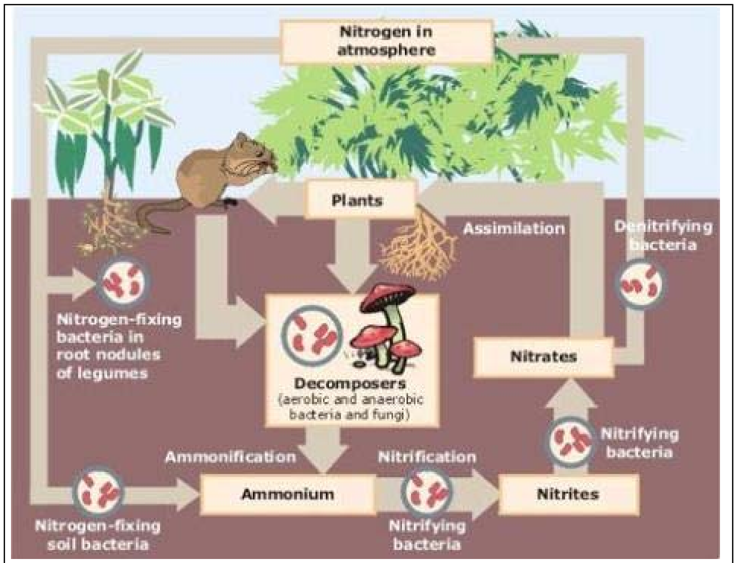
Humans have had an impact on the global carbon cycle as well. Humans burn **fossil fuels** for heating, cooking, manufacturing, and electricity. Burning fossil fuels releases carbon dioxide into the atmosphere.

Nitrogen Cycle

Nitrogen is another element necessary to the survival of all living things. Plants, for example, use nitrogen in the soil for growth. The air around us is 78% nitrogen gas. Organisms cannot use it in this form. Nitrogen must be "fixed," which means it must be changed to a different form, to be usable.

Look at the image of the nitrogen cycle. It shows nitrogen moving from the air, to the soil, into organisms, then back into the atmosphere again.

How does this nitrogen get fixed into a usable form? Bacteria and algae can fix nitrogen gas. Legumes, such as clover, alfalfa, and soy beans, have nodules on their roots. Nitrogen-fixing bacteria live in these nodules. They change nitrogen into ammonium. This ammonium can eventually be incorporated into plant tissue. Decomposers can also release ammonium into the soil. Additionally, there are bacteria that convert ammonium into nitrites and nitrates. Plants can take in nitrates. These nitrates can subsequently be passed to animals that eat the plants. Other types of bacteria can convert nitrates back to nitrogen gas, which then enters the atmosphere.



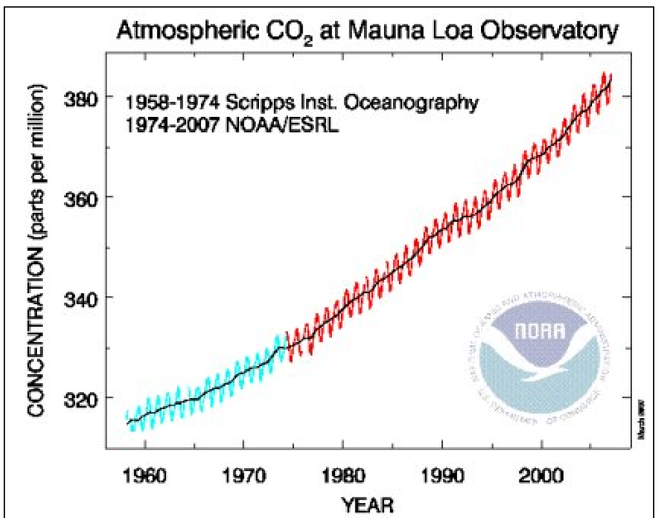
The nitrogen cycle

Making Connections

This lesson connected the biotic and abiotic forces affecting ecosystems. This lesson described the interdependence of organisms in an ecosystem. Top predators are important to a food web. Bacteria are key to fixing nitrogen so that it may be used by plants.

The section on the carbon cycle mentioned fossil fuels. The burning of fossil fuels can have detrimental effects on humans, animals, and plants in many biomes.

There are three main types of fossil fuels: coal, oil, and natural gas. They were formed many years ago. Earlier on in Earth's history, there were many swamps with large trees and leafy plants. Eventually, these plants died. They sank to the bottom of the swamps and oceans. The dead plant matter formed a layer called peat. Over time, many layers of rock formed over the peat. These rock layers squeezed all of the water out of the peat. As a result, coal, oil, and natural gas formed in this layer.



Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccg/trends)

The burning of fossil fuels emits carbon dioxide into the air. Carbon dioxide is considered to be a **greenhouse gas**. These types of gases trap heat in the Earth's atmosphere. They are the main contributors to **global warming**. The results of global warming could be devastating. Entire ecosystems might be lost. Sea levels could rise and cause floods. Human disease might increase as well.

Examine the graph shown here. It shows the amount of carbon dioxide in the atmosphere at a location in Hawaii. Data were taken from 1958-1974 and then 1974-2007. Notice how the atmospheric carbon dioxide level has increased every year since 1958. It continues to rise.