Energy Flow Through an Ecosystem

Inquire: Energy Flow Through Ecosystems

Overview

Ecosystems exist underground, on land, at sea, and in the air. Organisms in an ecosystem acquire energy in a variety of ways, which is transferred between trophic levels as energy flows from the base to the top of the food web, with some energy being lost at each transfer. There is energy lost at each trophic level, so the lengths of food chains are limited because there is a point where not enough energy remains to support a population of consumers. Fat soluble compounds biomagnify up a food chain causing damage to top consumers, even when environmental concentrations of a toxin are low.

Big Question: How do organisms acquire energy in a food web and in associated food chains?

Watch: Consequences of Food Webs: Biological Magnification

One of the most important consequences of ecosystem dynamics in terms of human impact is biomagnification. Biomagnification is the increasing concentration of persistent, toxic substances in organisms at each successive level of an ecosystem. These are substances that are fat soluble, not water soluble, and so are stored in the fat reserves of each organism. Many substances have been shown to biomagnify, including classical studies with the pesticide DDT.

DDT was a commonly used pesticide before its dangers to apex consumers, such as the bald eagle, became known. In aquatic ecosystems, organisms from each trophic level, or ecosystem level, consumed many organisms in the lower level, which caused DDT to increase in birds (apex consumers) that ate fish. Thus, the birds accumulated sufficient amounts of DDT to cause fragility in their eggshells. This effect increased egg breakage during nesting and was shown to have devastating effects on these bird populations. The use of DDT was banned in the United States in the 1970s.

Other substances that biomagnify are polychlorinated biphenyls (PCBs), which were used as coolant liquids in the United States until their use was banned in 1979. These substances are best studied in aquatic ecosystems, where predatory fish species accumulate very high concentrations of toxic substances that are at quite low concentrations in the environment and in producers. As illustrated in a study performed by NOAA in the Saginaw Bay of Lake Huron of the North American Great Lakes, PCB concentrations increased from the producers of the ecosystem (phytoplankton) through the different trophic levels of fish species. The apex consumer, the walleye, had more than four times the amount of PCBs compared to phytoplankton. Also, based on results from other studies, birds that eat these fish may have PCB levels at least one order of magnitude higher than those found in the lake fish.
Heavy metals such as mercury, lead, and cadmium also biomagnify. Concerns have been raised by the biomagnification of heavy metals, such as mercury and cadmium, in certain types of seafood. The United States Environmental Protection Agency recommends that pregnant women and young children should not consume any swordfish, shark, king mackerel, or tilefish because of their high mercury content. These individuals are advised to eat fish low in mercury: salmon, shrimp, pollock, and catfish. Biomagnification is a good example of how ecosystem dynamics can affect our everyday lives, even influencing the food we eat.

Read: Energy Flow Through an Ecosystem

Overview

An ecosystem is a community of living organisms and their abiotic (non-living) environment. Ecosystems can be small, such as the tide pools found near the rocky shores of many oceans, or large, such as those found in the tropical rainforest of the Amazon in Brazil.

There are three broad categories of ecosystems based on their general environment: freshwater, marine, and terrestrial. Within these three categories are individual ecosystem types based on the environmental habitat and organisms present.

Ecology of Ecosystems

Life in an ecosystem often involves competition for limited resources, which occurs both within a single species and between different species. Organisms compete for food, water, sunlight, space, and mineral nutrients. These resources provide the energy for metabolic processes and the matter to make up organisms’ physical structures. Other critical factors influencing community dynamics are the components of its physical environment: a habitat’s climate (including seasons, sunlight, and rainfall), elevation, and geology.

Freshwater ecosystems are the least common, occurring on only 1.8 percent of Earth's surface. These systems comprise lakes, rivers, streams, and springs; they are quite diverse, and support a variety of animals, plants, fungi, protists, and prokaryotes.

Marine ecosystems are the most common, comprising 75 percent of Earth's surface and consisting of three basic types: shallow ocean, deep ocean water, and deep ocean bottom. Shallow ocean ecosystems include extremely biodiverse coral reef ecosystems, yet the deep ocean water is known for large numbers of plankton (microscopic plants) and krill (small crustaceans) that support it.

These two environments are especially important to aerobic respirators worldwide, as the phytoplankton perform 40 percent of all photosynthesis on Earth. Although not as diverse as the other two, deep ocean bottom ecosystems contain a wide variety of marine organisms. Such ecosystems exist even at depths where light is unable to penetrate through the water.

Terrestrial ecosystems, also known for their diversity, are grouped into large categories called biomes. A biome is a large-scale community of organisms, primarily defined on land by the dominant plant types that exist in geographic regions of the planet with similar climatic conditions. Examples of biomes include tropical rainforests, savannas, deserts, grasslands, temperate forests, and tundras. Grouping these ecosystems into just a few biome categories obscures the great diversity of the individual ecosystems within them.
Ecosystems and Disturbance

Ecosystems are complex with many interacting parts. They are routinely exposed to various disturbances and changes in the environment that affect their compositions, such as yearly variations in rainfall and temperature. Many disturbances are a result of natural processes. For example, when lightning causes a forest fire and destroys part of a forest ecosystem, the ground is eventually populated with grasses, followed by bushes and shrubs, and later mature trees; thus, the forest is restored to its former state. This process is so universal that ecologists have given it a name — succession. The impact of environmental disturbances caused by human activities is now as significant as the changes shaped by natural processes. Human agricultural practices, air pollution, acid rain, global deforestation, overfishing, oil spills, and illegal dumping on land and in the ocean all have an impact on ecosystems.

Equilibrium is a dynamic state of an ecosystem in which, despite changes in species numbers and occurrence, biodiversity remains somewhat constant. In ecology, two parameters are used to measure changes in ecosystems: resistance and resilience. The ability of an ecosystem to remain at equilibrium in spite of disturbances is called resistance. The speed at which an ecosystem recovers equilibrium after being disturbed is called resilience. Ecosystem resistance and resilience are especially important when considering human impact. The nature of an ecosystem may change to such a degree that it can lose its resilience entirely. This process can lead to the complete destruction or irreversible altering of the ecosystem.

Food Chains and Food Webs

A food chain is a linear sequence of organisms through which nutrients and energy pass as one organism eats another. The levels in the food chain are producers, primary consumers, higher-level consumers, and finally decomposers. There is a single path through a food chain; each organism in a food chain occupies a specific trophic level (energy level), which is its position in the food chain or food web.

In many ecosystems, the base, or foundation, of the food chain consists of photosynthetic organisms (plants or phytoplankton), which are called producers. The organisms that consume the producers, the primary consumers, are herbivores. Secondary consumers are usually carnivores that eat the primary consumers. Tertiary consumers are carnivores that eat other carnivores. Higher-level consumers feed on the next lower trophic levels, and so on, up to the organisms at the top of the food chain: the apex consumers.

There is one problem when using food chains to describe most ecosystems. Even when all organisms are grouped into appropriate trophic levels, some of these organisms can also be fed on from multiple trophic levels. In addition, species feed on and are eaten by more than one species. A holistic model — which includes all the interactions between different species and their complex interconnected relationships with each other and with the environment — is a more accurate and descriptive model for ecosystems. A food web is a concept that accounts for the multiple trophic (feeding) interactions between each species and the many species it may feed on, or that feed on it. In a food web, the several trophic connections between each species and the other species that interact with it may cross multiple trophic levels. Thus, the matter and energy movements of virtually all ecosystems are more accurately described by food webs.

Two general types of food webs are often shown interacting within a single ecosystem. A grazing food web has plants or other photosynthetic organisms at its base, followed by herbivores and various
carnivores. A **detrital food web** consists of a base of organisms that feed on decaying organic matter (dead organisms), including decomposers (which break down dead and decaying organisms) and detritivores (which consume organic waste). These organisms are usually bacteria, fungi, and invertebrate animals that recycle organic material back into the biotic part of the ecosystem as they themselves are consumed by other organisms. As ecosystems require a method to recycle material from dead organisms, grazing food webs have an associated detrital food web. For example, in a meadow ecosystem, plants may support a grazing food web of different organisms, primary and other levels of consumers, while at the same time supporting a detrital food web of bacteria and fungi feeding off dead plants and animals. Simultaneously, a detrital food web can contribute energy to a grazing food web, as when a robin eats an earthworm.

**Reflect Poll: Biomagnification**

One of the most important consequences of ecosystem dynamics, in terms of human impact, is biomagnification. Biomagnification is the increasing concentration of persistent, toxic substances in organisms at each successive trophic level. Will your new knowledge change your diet?

- Yes
- No

**Expand: How Organisms Acquire Energy in a Food Web**

**Overview**

All living things require energy in one form or another. Energy is used by most complex metabolic pathways (usually in the form of ATP), especially those responsible for building large molecules from smaller compounds. Living organisms would not be able to assemble macromolecules (proteins, lipids, nucleic acids, and complex carbohydrates) from their monomers without a constant energy input.

**Acquiring Energy**

Food web diagrams illustrate how energy flows directionally through ecosystems. They can also indicate how efficiently organisms acquire and use energy, and how much remains for use by other organisms of the food web. Energy is acquired by living things in two ways: autotrophs harness light or chemical energy, and heterotrophs acquire energy through the consumption and digestion of other living or previously living organisms.

Photosynthetic and chemosynthetic organisms are **autotrophs**, which are organisms capable of synthesizing their own food (more specifically, capable of using inorganic carbon as a carbon source). Photosynthetic autotrophs (**photoautotrophs**) use sunlight as an energy source, and chemosynthetic autotrophs (**chemoautotrophs**) use inorganic molecules as an energy source. Autotrophs are critical for most ecosystems; they are the producer trophic level. Without these organisms, energy would not be available to other living organisms, and life itself would not be possible.

Photoautotrophs such as plants, algae, and photosynthetic bacteria are the energy source for a majority of the world’s ecosystems. These ecosystems are often described by grazing and detrital food webs. Photoautotrophs harness the sun’s solar energy by converting it to chemical energy in the form of ATP (and NADP). The energy stored in ATP is used to synthesize complex organic molecules, such as glucose. The rate at which photosynthetic producers incorporate energy from the sun is called **gross primary productivity**. However, not all of the energy incorporated by producers is available to other
organisms in the food web because producers must also grow and reproduce, which consumes energy. **Net primary productivity** is the energy that remains in the producers after accounting for these organisms’ respiration and heat loss. The net productivity is then available to the primary consumers at the next trophic level.

Chemoautotrophs are primarily bacteria and archaea that are found in rare ecosystems where sunlight is not available, such as those associated with dark caves or hydrothermal vents at the bottom of the ocean. Many chemoautotrophs in hydrothermal vents use hydrogen sulfide (H$_2$S), which is released from the vents as a source of chemical energy; this allows them to synthesize complex organic molecules, such as glucose, for their own energy and, in turn, supplies energy to the rest of the ecosystem.

**Lesson Toolbox**

**Additional Resources and Readings**

An Amoeba Sisters video covering food webs and energy flow
- Link to resource: https://www.youtube.com/watch?v=-oVavgmveyY

A link allowing you to explore trophic cascades
- Link to resource: https://www.hhmi.org/biointeractive/exploring-trophic-cascades

A short video telling the story of keystone species and trophic cascades
- Link to resource: https://www.hhmi.org/biointeractive/some-animals-are-more-equal-others-keystone-species-and-trophic-cascades

**Lesson Glossary**

**autotrophs**: an organism capable of synthesizing its own food molecules from smaller inorganic molecules  
**apex consumers**: an organism at the top of the food chain  
**biome**: a large-scale community of organisms, primarily defined on land by the dominant plant types that exist in geographic regions of the planet with similar climatic conditions  
**chemoautotrophs**: an organism capable of synthesizing its own food using energy from inorganic molecules  
**detrital food web**: a type of food web that is supported by dead or decaying organisms rather than by living autotrophs; these are often associated with grazing food webs within the same ecosystem  
**ecosystem**: a community of living organisms and their interactions with their abiotic environment  
**equilibrium**: the steady state of a system in which the relationships between elements of the system do not change  
**food chain**: a linear sequence of trophic (feeding) relationships of producers, primary consumers, and higher level consumers  
**food web**: a web of trophic (feeding) relationships among producers, primary consumers, and higher level consumers in an ecosystem  
**grazing food web**: a type of food web in which the producers are either plants (on land) or phytoplankton (in water); often associated with a detrital food web within the same ecosystem  
**gross primary productivity**: the rate at which photosynthetic producers incorporate energy from the sun
**net primary productivity**: the energy that remains in the producers after accounting for the organisms’ respiration and heat loss

**photoautotrophs**: an organism that uses sunlight as an energy source to synthesize its own food molecules

**primary consumers**: the trophic level that obtains its energy from the producers of an ecosystem

**producers**: the trophic level that obtains its energy from sunlight, inorganic chemicals, or dead or decaying organic material

**resilience**: the speed at which an ecosystem recovers equilibrium after being disturbed

**resistance**: the ability of an ecosystem to remain at equilibrium in spite of disturbances

**secondary consumers**: a trophic level in an ecosystem, usually a carnivore that eats a primary consumer

**tertiary consumers**: a trophic level in an ecosystem, usually carnivores that eat other carnivores

**trophic level**: the position of a species or group of species in a food chain or a food web

### Check Your Knowledge

1. There is a single path through a food chain.
   - a. True
   - b. False

2. A grazing food web has plants or other photosynthetic organisms at its base, followed by herbivores and various carnivores.
   - a. True
   - b. False

3. Food web diagrams illustrate how energy flows directionally through ecosystems.
   - a. True
   - b. False

**Answer Key:**
1. A  2. A  3. A

### Citations

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