

Chapter 55: Ecosystems

1. *What is an ecosystem?*

An ecosystem is the sum of all the organisms living in a given area and the abiotic factors with which they interact.

2. *Where does energy enter most ecosystems?*

Energy enters most ecosystems as sunlight. It is converted to chemical energy by autotrophs, passed to heterotrophs in the organic compounds of food, and dissipated as heat. Chemical elements, such as carbon, are cycled among abiotic and biotic components of the ecosystem. Unlike matter, energy cannot be recycled. An ecosystem must be powered by a continuous influx of energy from an external source (in most cases, the sun).

3. *Besides the energy flow described in #2, chemicals such as carbon and nitrogen cycle through ecosystems.*

Energy flows through an ecosystem and matter cycles within and through them. Matter and energy cannot be created or destroyed.

5. *What trophic level supports all others?*

The trophic level that ultimately supports all others consists of autotrophs, the primary producers of the ecosystem.

6. *List three groups of organisms that are photosynthetic autotrophs.*

Plants, algae, and photosynthetic prokaryotes are the biosphere's main autotrophs.

7. *What are the primary producers of deep-sea vents?*

Chemosynthetic prokaryotes are the primary producers in ecosystems such as deep-sea hydrothermal vents and places deep under the ground or ice.

9. *What are detritivores and what is their importance in chemical cycling?*

Detritivores (decomposers) are consumers that get their energy from detritus, nonliving organic material such as the remains of dead organisms, feces, fallen leaves, and wood. Prokaryotes and fungi secrete enzymes that digest organic material; they then absorb the breakdown products, linking the consumers and primary producers in an ecosystem. Detritivores convert organic matter from all trophic levels to inorganic compounds usable by primary producers, closing the loop of an ecosystem's chemical cycling. Producers can then recycle these elements into organic compounds. If decomposition stopped, life would cease as detritus piled up and the supply of ingredients needed to synthesize new organic matter was exhausted.

10. *Give examples of animals from different trophic levels.*

Cow: primary consumer; Grass: primary producer; Human: secondary consumer; Mushroom: detritivore

11. *What is primary production? Distinguish between gross primary production and net primary production.*

In most ecosystems, the amount of light energy converted to chemical energy in the form of organic compounds by autotrophs during a given time period is the ecosystem's primary production. Total primary production in an ecosystem is known as that ecosystem's gross primary production (GPP) – the amount of energy from light (or chemicals, in chemoautotrophic systems) converted to the chemical energy of organic molecules per unit time. Not all of this production is stored as organic material in the primary producers because they use some of the molecules as fuel in their own cellular respiration. Net primary production (NPP) is equal to gross primary production minus the energy used by the primary producers for their autotrophic respiration (R_a). On average, NPP is about one-half of GPP.

12. *Write an equation that shows the relationship between gross and net primary production.*

$$\text{NPP} = \text{GPP} - R_a$$

13. Why is net primary production, or the amount of new biomass/unit of time, the key measurement to ecologists?

NPP represents the storage of chemical energy that will be available to consumers in the ecosystem.

14. Which ecosystem would tend to have a greater biomass/unit area, a prairie or a tropical rain forest? Explain.

The rainforest would tend to have a greater biomass per unit area, because it has a greater diversity of life in greater density.

15. Describe a technique for measuring net primary production in an aquatic environment.

Because chlorophyll captures visible light, photosynthetic organisms absorb more light at visible wavelengths (~380–750 nm) than at near-infrared wavelengths (750–1,100 nm). Scientists use this difference in absorption to estimate the rate of photosynthesis in different regions of the globe using satellites.

16. What are some factors that limit primary productivity in aquatic ecosystems?

The depth of light penetration affects primary production throughout the photic zone of an ocean or lake. About half of the solar radiation is absorbed in the first 15m of water. Even in “clear” water, only 5–10% of the radiation may reach a depth of 75m. More than light, nutrients limit primary production in most oceans and lakes.

17. What is a limiting nutrient?

A limiting nutrient is the element that must be added for production to increase. The nutrient most often limiting marine production is either nitrogen or phosphorus. Concentrations of these nutrients are typically low in the photic zone because they are rapidly taken up by phytoplankton and because detritus tends to sink.

18. What are common sources of nitrates and phosphates that can increase phytoplankton growth?

Adding the micronutrient iron stimulates the growth of cyanobacteria that fix additional atmospheric oxygen.

19. What is eutrophication? What factors contribute to eutrophication?

Eutrophication is the excessive richness of nutrients in a lake or other body of water, frequently due to runoff from the land, which causes a dense growth of plant life and death of animal life from lack of oxygen. Adding a nonlimiting nutrient, even one that is scarce, will not stimulate production. Conversely, adding more of the limiting nutrient will increase production until some other nutrient becomes limiting.

20. What is trophic efficiency?

Trophic efficiency is the percentage of production transferred from one trophic level to the next. Trophic efficiencies must always be less than production efficiencies (the percentage of energy stored in assimilated food that is not used for respiration) because they take into account not only the energy lost through respiration and contained in feces, but also the energy in organic material in a lower trophic level that is not consumed by the next trophic level.

21. What percentage of energy available at one trophic level is generally available at the next?

Trophic efficiencies are generally only ~10% and range from ~5% to ~20% depending on the type of ecosystem.

22. If a food chain with 1,000 joules is grass>grasshopper>lizard>crow, how much energy is found at the level of the crow?

~1 joule

23. Explain why the second pyramid of biomass is inverted. ✍

Most biomass pyramids show a sharp decrease in biomass at successively higher trophic levels. However, in some aquatic ecosystems, such as the English Channel, a small standing crop of primary producers (phytoplankton) with a short turnover time supports a large standing crop of primary consumers (zooplankton).

24. Why do people who have limited diets in overpopulated parts of the world eat low on the food chain?

Eating meat is a relatively inefficient way of tapping photosynthetic production. The same pound of soybeans that a person could eat for protein produces only a fifth of a pound of beef or less when fed to a cow. Worldwide agriculture

could successfully feed many more people and require less cultivated land if humans all fed more efficiently – as primary consumers, eating plant material.

25. *Describe the water cycle.*

The main processes driving the water cycle are evaporation of liquid water by solar energy, condensation of water vapor into clouds, and precipitation. Transpiration by terrestrial plants also moves large volumes of water into the atmosphere. Surface and groundwater flow can return water to the oceans, completing the water cycle. The oceans contain 97% of the water in the biosphere. Approximately 2% is bound in glaciers and polar ice caps, and the remaining 1% is in lakes, rivers, and groundwater, with a negligible amount in the atmosphere.

26. *Describe the carbon cycle.*

Photosynthesis by plants and phytoplankton removes substantial amounts of atmospheric CO₂ each year. This quantity is approximately equaled by CO₂ added to the atmosphere through cellular respiration by producers and consumers. The burning of fossil fuels and wood fuel is adding significant amounts of additional CO₂ to the atmosphere. Over geologic time, volcanoes are also a substantial source of CO₂.

Summary equation for photosynthesis: $6\text{CO}_2 + 6\text{H}_2\text{O} + \text{sunlight} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

Summary equation for cellular respiration: $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy}$

27. *Describe the nitrogen cycle.*

The major pathway for nitrogen to enter an ecosystem is via nitrogen fixation, the conversion of N₂ to forms that can be used to synthesize organic nitrogen compounds. Certain bacteria, as well as lightning, fix nitrogen naturally. Nitrogen inputs from human activities now outpace natural inputs on land. Two major contributors are industrially produced fertilizers and legume crops that fix nitrogen via bacteria in their root nodules. Other bacteria in soil convert nitrogen to different forms. Some bacteria carry out denitrification, the reduction of nitrate to nitrogen gases. Human activities also release large quantities of reactive nitrogen gases, such as nitrogen oxides, to the atmosphere.

28. *What effect has deforestation been shown to have on chemical cycling?*

Experimental deforestation of a watershed dramatically increased the flow of water and minerals leaving the watershed. Over three years, water runoff from the newly deforested watershed was 30–40% greater than in a control watershed, apparently because there were no plants to absorb and transpire water from the soil. The concentration of Ca²⁺ in the creek increased 4-fold, the concentration of K⁺ increased by a factor of 15, and the concentration of nitrate in the creek increased 60-fold!

29. *How has agriculture affected nitrogen cycling? What are some negative consequences of nutrient enrichment?*

Human activity often removes nutrients from one part of the biosphere and adds them to another. Nutrients in farm soil may run off into streams and lakes, depleting nutrients in one area, increasing them in another, and altering chemical cycles in both. Humans have also added entirely novel materials – some of them toxic – to ecosystems. In any area under extensive agriculture, the natural store of nutrients eventually becomes exhausted. Nitrogen is the main nutrient element lost through agriculture. Recent studies indicate that human activities have more than doubled Earth's supply of fixed nitrogen available to primary producers. Industrial fertilizers provide the largest additional nitrogen source. Fossil fuel combustion also releases nitrogen oxides; the nitrogen ultimately enters ecosystems as nitrate.

A problem arises when the nutrient level in an ecosystem exceeds the critical load, the amount of added nutrient, usually nitrogen or phosphorus, that can be absorbed by plants without damaging ecosystem integrity. Nitrogenous minerals in the soil that exceed the critical load eventually leach into groundwater or run off into freshwater and marine ecosystems, contaminating water supplies and killing fish. Fish and other marine animals are disappearing from some of the most economically important waters in the United States. Nutrient runoff can also lead to the eutrophication of lakes.

30. *In what ways have human activities contributed to acid precipitation? What are some of its negative consequences?*

Humans release an immense variety of toxic chemicals, including thousands of synthetic compounds previously unknown in nature, with little regard for the ecological consequences. Organisms acquire toxic substances from the environment along with nutrients or water.

31. *Explain the process of biological magnification.*

Humans release an immense variety of toxic chemicals, including thousands of synthetic compounds previously unknown in nature, with little regard for the ecological consequences. Organisms acquire toxic substances from the environment along with nutrients or water. Some of the poisons are metabolized or excreted, but others accumulate in

specific tissues, often fat. One of the reasons accumulated toxins are particularly harmful is that they become more concentrated in successive trophic levels of a food web. This phenomenon, called biological magnification, occurs because the biomass at any given trophic level is produced from a much larger biomass ingested from the level below. Thus, top-level carnivores tend to be most severely affected by toxic compounds in the environment. A class of industrially synthesized compounds that have demonstrated biological magnification are the chlorinated hydrocarbons, which include the industrial chemicals called PCBs (polychlorinated biphenyls) and many pesticides, such as DDT, a chemical used to control insects such as mosquitoes and agricultural pests.

32. What is meant by the greenhouse effect?

Rising concentrations of long-lived greenhouse gases such as CO₂ are increasing plant productivity and changing Earth's heat budget. Much of the solar radiation that strikes the planet is reflected back into space. Although CO₂, water vapor, and other greenhouse gases in the atmosphere are transparent to visible light, they intercept and absorb much of the infrared radiation Earth emits, re-reflecting some of it back toward Earth. This process retains some of the solar heat. If it were not for this greenhouse effect, the average air temperature at Earth's surface would be a frigid -18°C.

33. What is contributing to the great increase in atmospheric carbon dioxide? What are potential effects of this increase?

Scientists are concerned that fossil fuel burning could contribute to global warming. By the end of the 21st century, the atmospheric CO₂ concentration is predicted to more than double, increasing average global temperature by about 3°C. An increase of only 1.3°C would make the world warmer than at any time in the past 100,000 years. A warming trend would also alter the geographic distribution of precipitation, likely making agricultural areas of the central United States much drier, for example. Higher temperatures also cause polar ice caps to melt and increase the likelihood of fires. Many organisms, especially plants that cannot disperse rapidly over long distances, may not be able to survive the rapid climate change projected to result from global warming. Deforestation currently accounts for ~12% of the greenhouse gas emissions.

34. How is atmospheric ozone depleted? What are projected effects of this depletion?

Life on Earth is protected from the damaging effects of UV radiation by a layer of ozone located in the stratosphere 17–25 km above Earth's surface. The destruction of atmospheric ozone results primarily from the accumulation of chlorofluorocarbons (CFCs), chemicals once widely used in refrigeration and manufacturing. In the stratosphere, chlorine atoms released from CFCs react with ozone, reducing it to molecular O₂. Subsequent chemical reactions liberate the chlorine, allowing it to react with other ozone molecules in a catalytic chain reaction. At the more heavily populated middle latitudes, ozone levels have decreased 2–10% during the past 20 years.

Decreased ozone levels in the stratosphere increase the intensity of UV rays reaching Earth's surface. Some scientists expect increases in cataracts and both lethal and nonlethal forms of skin cancer among humans, as well as unpredictable effects on crops and natural communities, especially the phytoplankton that are responsible for a large proportion of Earth's primary production. As a consequence of many countries' relatively rapid responses to the ozone hole, chlorine concentrations in the stratosphere have stabilized and ozone depletion is slowing. Even though CFC emissions are close to zero today, however, chlorine molecules already in the atmosphere will continue to influence stratospheric ozone levels for at least 50 years.