UG CBCS Semester-IV (MJC-7: Ecology)

Carbon Cycle

The internal cycling of nutrients within the ecosystem is a story of biological processes. But not every transformation of elements in the ecosystem is biologically mediated. Many chemical reactions take place in abiotic components of the ecosystem: the atmosphere, water, soil, and parent material. The weathering of rocks and minerals releases certain elements into the soil and water, making them available for uptake by plants. The energy from lightning produces small amounts of ammonia from molecular nitrogen and water in the atmosphere, providing an input of nitrogen to aquatic and terrestrial ecosystems. Other processes, such as the sedimentation of calcium carbonate in marine environments, remove elements from the active process of internal cycling. Each element has its own story, but all nutrients flow from the nonliving to the living and back to the nonliving components of the ecosystem in a more or less cyclic path known as the **biogeochemical cycle** (from *bio,* “living”; *geo* for the rocks and soil; and *chemical* for the processes involved).

There are two basic types of biogeochemical cycles: gaseous and sedimentary. This classification is based on the primary source of nutrient input to the ecosystem. In gaseous cycles, the main pools of nutrients are the atmosphere and the oceans. For this reason, gaseous cycles are distinctly global. The gases most important for life are nitrogen, oxygen, and carbon dioxide. These three gases—in stable quantities of 78 percent, 21 percent, and 0.03 percent, respectively—are the dominant components of Earth’s atmosphere.

In sedimentary cycles, the main pool is the soil, rocks, and minerals. The mineral elements required by living organisms come initially from inorganic sources. Available forms occur as salts dissolved in soil water or in lakes, streams, and seas. The mineral cycle varies from one element to another, but essentially it consists of two phases: the rock phase and the salt solution phase. Mineral salts come directly from Earth’s crust through weathering. The soluble salts then enter the water cycle. With water, the salts move through the soil to streams and lakes and eventually reach the seas, where they remain indefinitely. Other salts return to Earth’s crust through sedimentation. They become incorporated into salt beds, silts, and limestone. After weathering, they enter the cycle again.

There are many different kinds of sedimentary cycles. Cycles such as the sulfur cycle are a hybrid of the gaseous and the sedimentary because they have major pools in Earth’s crust as well as in the atmosphere. Other cycles, such as the phosphorus cycle, have no significant gaseous pool; the element is released from rock and deposited in both the shallow and deep sediments of the sea. Gaseous and sedimentary cycles involve biological and nonbiological processes. Both cycles are driven by the flow of energy through the ecosystem, and both are tied to the water cycle. Water is the medium that moves elements and other materials through the ecosystem. Without the cycling of water, biogeochemical cycles would cease. Although the biogeochemical cycles of the various essential nutrients required by autotrophs and heterotrophs differ in detail, from the perspective of the ecosystem all biogeochemical cycles have a common structure. They share three basic components: inputs, internal cycling, and outputs.

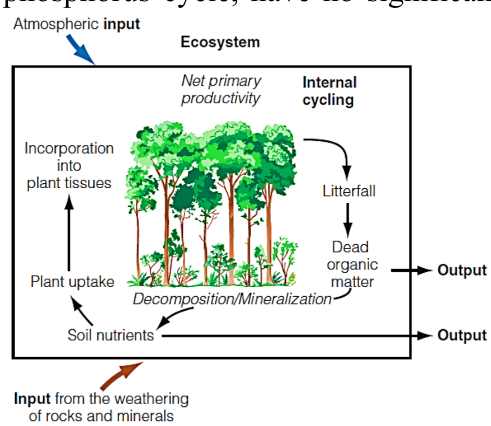
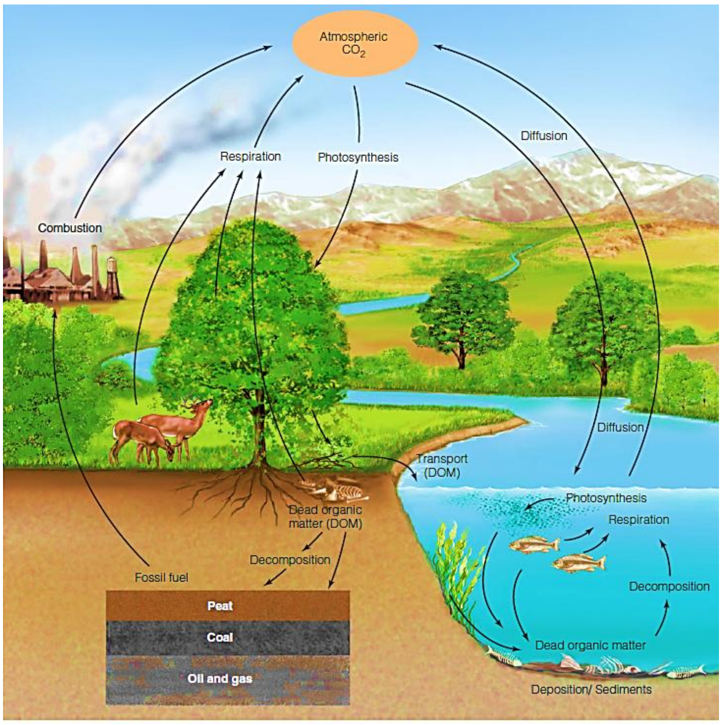


Figure 23.1 A generalized representation of the biogeochemical cycle of an ecosystem. The three common components—inputs, internal cycling, and outputs—are shown in bold. Key processes involved in the internal cycling of nutrients within ecosystems, net primary productivity and decomposition, are shown in italics.

The Carbon Cycle Is Closely Tied to Energy Flow

Carbon, a basic constituent of all organic compounds, is involved in the fixation of energy by photosynthesis. Carbon is so closely tied to energy flow that the two are inseparable. In fact, we often express ecosystem productivity in terms of grams of carbon fixed per square meter per year. The source of all carbon, both in living organisms and fossil deposits, is carbon dioxide (CO_2) in the atmosphere and the waters of Earth. Photosynthesis draws CO_2 from the air and water into the living component of the ecosystem. Just as energy flows through the grazing food chain, carbon passes to herbivores and then to carnivores. Primary producers and consumers release carbon back to the atmosphere in the form of CO_2 by respiration. The carbon in plant and animal tissue eventually goes to the reservoir of dead organic matter. Decomposers release it to the atmosphere through respiration. Figure shows the cycling of carbon through a terrestrial ecosystem. The difference between the rate of carbon uptake by plants in photosynthesis and release by respiration is the net primary productivity (in units of carbon). The difference between the rate of carbon uptake in photosynthesis and the rate of carbon loss due to autotrophic and heterotrophic respiration is the **net ecosystem productivity**.

Several processes, particularly the rates of primary productivity and decomposition, determine the rate at which carbon cycles through the ecosystem. Both processes are influenced strongly by environmental conditions such as temperature and precipitation. In warm, wet ecosystems such as a tropical rain forest, production and decomposition rates are high, and carbon cycles through the ecosystem quickly. In cool, dry ecosystems, the process is slower. In ecosystems where temperatures are very low, decomposition is slow, and dead organic matter accumulates. In swamps and marshes, where dead material falls into the water, organic material does not completely decompose. When stored as raw humus or peat, carbon circulates slowly. Over geologic time, this buildup of partially decomposed organic matter in swamps and marshes has formed fossil fuels (oil, coal, and natural gas). Similar cycling takes place in freshwater and marine environments.



ıre 23.2 The carbon cycle as it occurs in both terrestrial and aquatic ecosystems.

Phytoplankton uses the carbon dioxide that diffuses into the upper layers of water or is present as carbonates and converts it into plant tissue. The carbon then passes from the primary producers through the aquatic food chain. Carbon dioxide produced through respiration is either reused or reintroduced to the atmosphere by diffusion from the water surface to the surrounding air. Significant amounts of carbon can be bound as carbonates in the bodies of mollusks and foraminifers and incorporated into their exoskeletons (shells, etc.). Some of these carbonates dissolve back into solution, and some become buried in the bottom mud at varying depths when the organisms die. Because it is isolated from biotic activity, this carbon is removed from cycling. Upon incorporation into bottom sediments over geologic time, it may appear in coral reefs and limestone rocks.

Carbon Cycling Varies Daily and Seasonally

If you were to measure the concentration of carbon dioxide in the atmosphere above and within a forest on a summer day, you would discover that it fluctuates throughout the day. At daylight when photosynthesis begins, plants start to withdraw carbon dioxide from the air, and the concentration declines sharply. By afternoon when the temperature is increasing and relative humidity is decreasing, the rate of photosynthesis declines, and the concentration of carbon dioxide in the air surrounding the canopy increases. By sunset, photosynthesis ceases (carbon dioxide is no longer being withdrawn from the atmosphere), respiration increases, and the atmospheric concentration of carbon dioxide increases sharply. A similar diurnal fluctuation occurs in aquatic ecosystems.

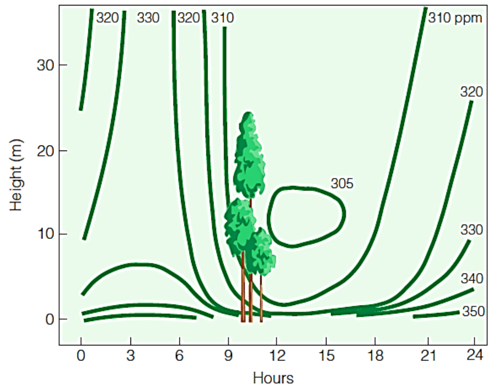


Figure 23.3 Daily flux of CO_2 in a forest. Isopleths (lines) define concentration gradients. Note the consistently high level of CO_2 on the forest floor—the site of microbial respiration. Atmospheric CO_2 in the forest is lowest from midmorning to late afternoon. CO_2 levels are highest at night, when photosynthesis shuts down and respiration pumps CO_2 into the atmosphere.
(Adapted from Baumgartner 1968.)

Likewise, the production and use of carbon dioxide undergoes a seasonal fluctuation relating both to the temperature and the timing of the growing and dormant seasons. With the onset of the growing season when the landscape is greening, the atmospheric concentration begins to drop as plants withdraw carbon dioxide through photosynthesis. As the growing season reaches its end, photosynthesis declines or ceases, respiration is the dominant process, and atmospheric concentrations of carbon dioxide rise. Although these patterns of seasonal rise and decline occur in both aquatic and terrestrial ecosystems, the fluctuations are much greater in terrestrial environments. As a result, these fluctuations in atmospheric concentrations of carbon dioxide are more pronounced in the Northern Hemisphere with its much larger land area.

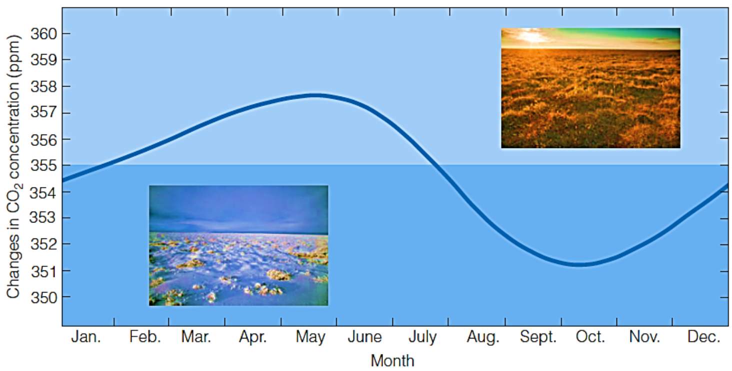


Figure 23.4 Variation in atmospheric concentration of CO_2 during a typical year at Barrow, Alaska. Concentrations increase during the winter months, declining with the onset of photosynthesis during the growing season (May–June).
(Adapted from Pearman and Hyson 1981.)

The Global Carbon Cycle Involves Exchanges among the Atmosphere, Oceans, and Land

The carbon budget of Earth is closely linked to the atmosphere, land, and oceans and to the mass movements of air around the planet. Earth contains about 1023 g of carbon, or 100 million Gt [Gt is a gigaton, equal to 1 billion (10^9) metric tons, or 10^{15} g]. All but a small fraction of carbon is buried in sedimentary rocks and is not actively involved in the global carbon cycle. The carbon pool involved in the global carbon cycle amounts to an estimated 55,000 Gt. Fossil fuels, created by the burial of partially decomposed organic matter, account for an estimated 10,000 Gt. The oceans contain the vast majority of the active carbon pool, about 38,000 Gt, mostly as bicarbonate and carbonate ions.

Dead organic matter in the oceans accounts for 1650 Gt of carbon; living matter, mostly phytoplankton (primary producers), accounts for 3 Gt. The terrestrial biosphere (all terrestrial ecosystems) contains an estimated 1500 Gt of carbon as dead organic matter and 560 Gt as living matter (biomass). The atmosphere holds about 750 Gt of carbon. In the ocean, the surface water acts as the site of main exchange of carbon between atmosphere and ocean. The ability of the surface waters to take up CO_2 is governed largely by the reaction of CO_2 with the carbonate ion to form bicarbonates. In the surface water, carbon circulates physically by means of currents and biologically through photosynthesis by phytoplankton and movement through the food chain. The net exchange of CO_2 between the oceans and atmosphere due to both physical and biological processes results in a net uptake of 1 Gt per year by the oceans, and burial in sediments accounts for a net loss of 0.5 Gt of carbon per year.

Uptake of CO_2 from the atmosphere by terrestrial ecosystems is governed by gross production (photosynthesis). Losses are a function of autotrophic and heterotrophic respiration; the latter being dominated by microbial decomposers. Until recently, exchanges of CO_2 between the landmass and the atmosphere (uptake in photosynthesis and release by respiration and decomposition) were believed to be nearly in equilibrium. However, more recent research suggests that the terrestrial surface is acting as a carbon sink, with a net uptake of CO_2 from the atmosphere. Of considerable importance in the terrestrial carbon cycle are the relative proportions of carbon stored in soils and in living vegetation (biomass). Carbon stored in soils includes dead organic matter on the soil surface and in the underlying mineral soil. Estimates place the amount of soil carbon at 1500 Gt compared with 560 Gt in living biomass.

The average amount of carbon per volume of soil increases from the tropical regions poleward to the boreal forest and tundra. Low values for the tropical forest reflect high rates of decomposition, which compensate for high productivity and litterfall. Frozen tundra soil and waterlogged soils of swamps and marshes have the greatest accumulation of dead organic matter because factors such as low temperature, saturated soils, and anaerobic conditions function to inhibit decay.

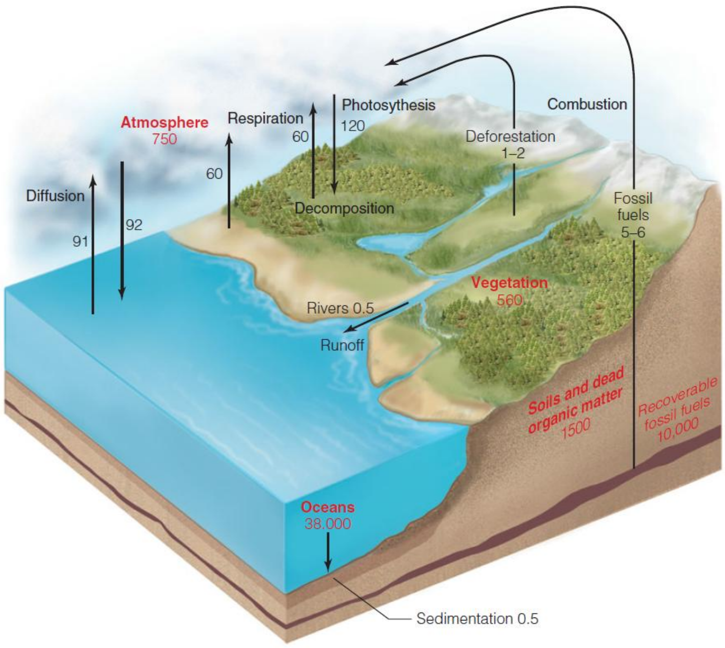


Figure 23.5 The global carbon cycle. The sizes of the major pools of carbon are labelled in red, and arrows indicate the major exchanges (fluxes) among them. All values are in gigatons (Gt) of carbon, and exchanges are on an annual timescale. The largest pool of carbon, geologic, is not included due to the slow rates (geologic timescale) of transfer with other active pools.
(Adapted from Edmonds 1992.)