11.6 Global biogeochemical cycles

Nutrients are moved over vast distances by winds in the atmosphere and by the moving waters of streams and ocean currents. There are no boundaries, either natural or political. It is appropriate, therefore, to conclude this chapter by moving to an even larger spatial scale to examine global biogeochemical cycles.

11.6.1 The hydrological cycle

The principal source of water is the oceans; radiant energy makes water evaporate into the atmosphere, winds distribute it over the surface of the globe and precipitation brings it down to the Earth's surface (with a net movement of atmospheric water from oceans to continents), where it may be stored temporarily in soils, lakes and icefields (Figure 11.15). Loss occurs from the land through evaporation and transpiration or as liquid flow through stream channels and groundwater aquifers, eventually to return to the sea. The major pools of water occur in the oceans (97.3% of the total for the biosphere), the ice of polar icecaps and glaciers (2.06%), deep in the ground water (0.67%) and in rivers and lakes (0.01%) (Berner & Berner, 1987). The proportion that is in transit at any time is very small – water draining through the soil, flowing along rivers and present as clouds and vapor in the atmosphere – together this constitutes only about 0.08% of the total. However, this small percentage plays a crucial role, both by supplying the requirements for the survival of living organisms and for community productivity and because so many chemical nutrients are transported with the water as it moves.

The hydrological cycle would proceed whether or not a biota was present. However, terrestrial vegetation can modify the fluxes that occur. Vegetation can intercept water at two points on this journey, stopping some from reaching the ground water and moving it back into the atmosphere, by: (i) catching some in foliage from which it evaporates; and (ii) preventing some from draining from the soil water by taking it up via the roots into the plant's transpiration stream. We have seen earlier how cutting down the forest in a catchment in Hubbard Brook (see Section 1.3.3) increased the throughput of water to streams, along with its load of dissolved and particulate matter. It is small wonder that large-scale

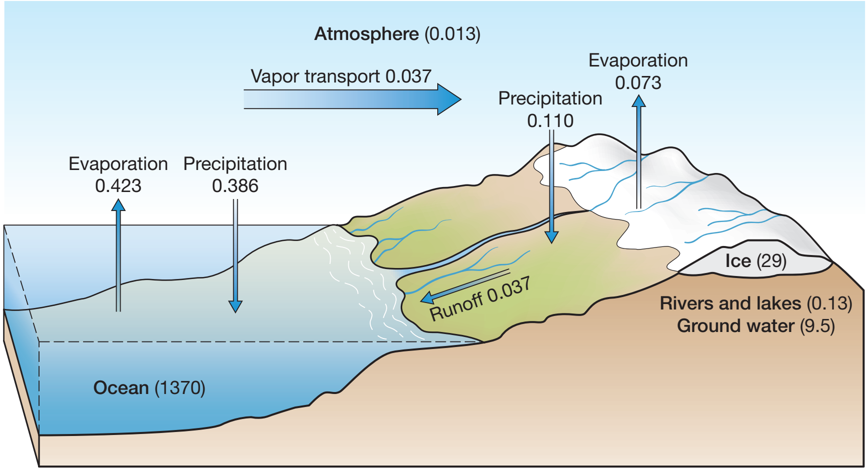


Figure 11.15

The hydrological cycle, showing volumes of water in the 'reservoirs' of oceans, ice (polar and glacier), rivers and lakes, ground water and atmosphere (units of 10^6 km^3), and on the move as precipitation, runoff, evaporation and vapor transport (arrows: units of 10^6 km^3 yr^{-1}).

AFTER BERNER & BERNER, 1987

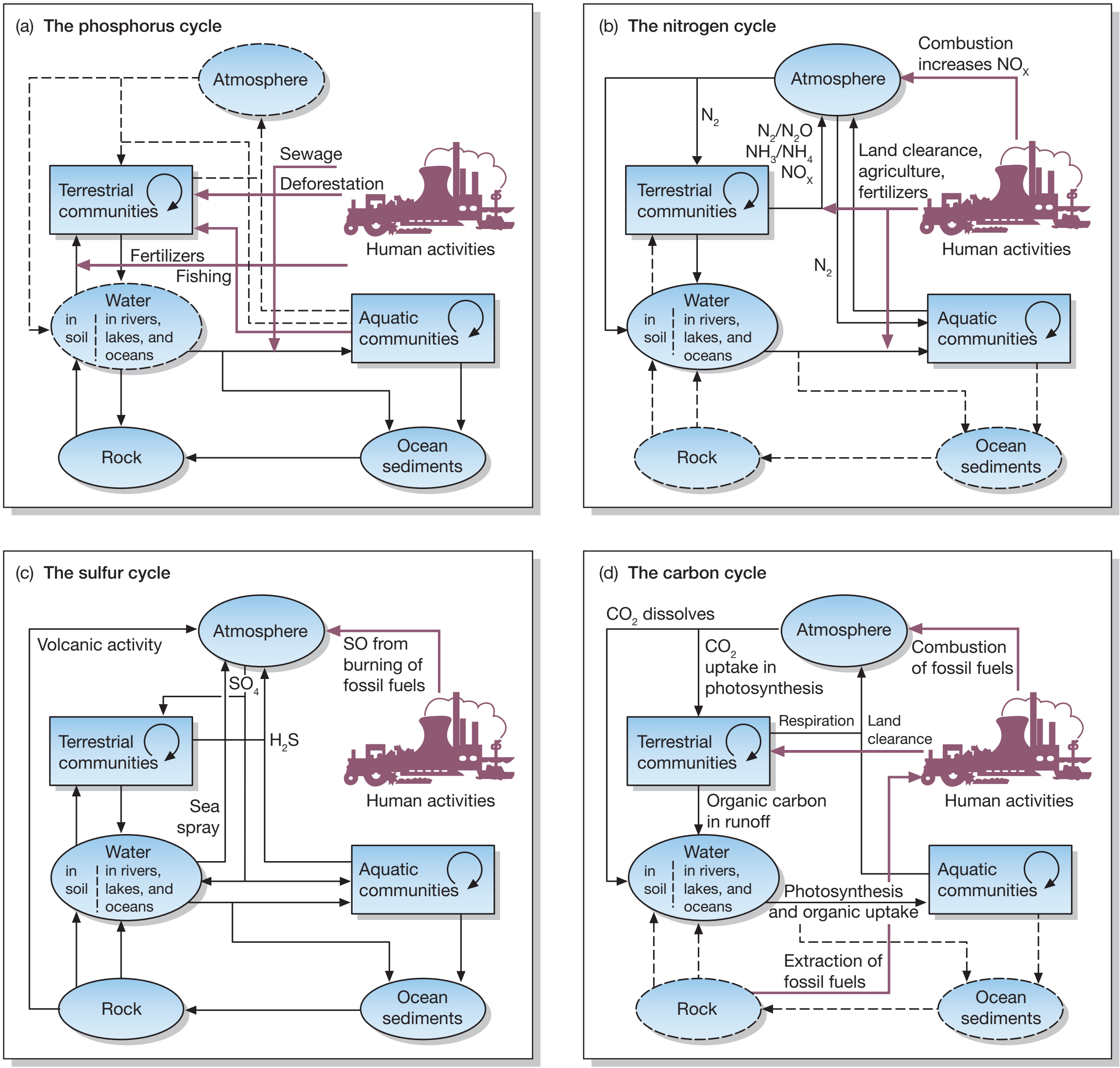


Figure 11.16

The major global pathways of nutrients between the abiotic 'reservoirs' of atmosphere, water (hydrosphere) and rock and sediments (lithosphere), and the biotic 'reservoirs' constituted by terrestrial and aquatic communities. Human activities (maroon arrows) change nutrient fluxes in terrestrial and aquatic communities by releasing extra nutrients into both atmosphere and water. Cycles are presented for four important nutrient elements: (a) phosphorus, (b) nitrogen, (c) sulfur and (d) carbon. Insignificant compartments and fluxes are represented by dashed lines.

deforestation around the globe, usually to create new agricultural land, can lead to loss of topsoil, nutrient impoverishment and increased severity of flooding. Water is a very valuable commodity, and this is reflected in the difficult political exercise of dealing with competing demands – to divert river water for hydroelectric power generation or agricultural irrigation as opposed to maintaining the intrinsic values of an unmanipulated river.

The world's major abiotic reservoirs for nutrients are illustrated in Figure 11.16. We now consider these cycles in turn.

11.6.2 The phosphorus cycle

The principal stocks of phosphorus occur in the waters of soil, rivers, lakes and oceans and in rocks and ocean sediments. The phosphorus cycle may be described as a sedimentary cycle because of the general tendency for mineral phosphorus to be carried from the land inexorably to the oceans where ultimately it becomes incorporated in the sediments (Figure 11.16a).

the life history of a phosphorus atom

A 'typical' phosphorus atom, released from the rock by chemical weathering, may enter and cycle within the terrestrial community for years, decades or centuries before it is carried via the ground water into a stream. Within a short time of entering the stream (weeks, months or years), the atom is carried to the ocean. It then makes, on average, about 100 round trips between surface and deep waters, each lasting perhaps 1000 years. During each trip, it is taken up by surface-dwelling organisms, before eventually settling into the deep again. On average, on its 100th descent (after 10 million years in the ocean) it fails to be released as soluble phosphorus, but instead enters the bottom sediment in particulate form. Perhaps 100 million years later, the ocean floor is lifted up by geological activity to become dry land. Thus, our phosphorus atom will eventually find its way back via a river to the sea, and to its existence of cycle (biotic uptake and decomposition) within cycle (ocean mixing) within cycle (continental uplift and erosion).

11.6.3 The nitrogen cycle

the nitrogen cycle has an atmospheric phase of overwhelming importance

The atmospheric phase predominates in the global nitrogen cycle, in which nitrogen fixation and denitrification by microbial organisms are of particular importance (Figure 11.16b). However, nitrogen from certain geological sources may also be locally significant in fueling productivity in terrestrial and freshwater communities (Holloway et al., 1998, Thompson et al., 2001). The magnitude of the flux in streamflow from terrestrial to aquatic communities is relatively small, but it is by no means insignificant for the aquatic systems involved. This is because nitrogen is one of the two elements (along with phosphorus) that most often limit plant growth. Finally, there is a small annual loss of nitrogen to ocean sediments.

11.6.4 The sulfur cycle

Three natural biogeochemical processes release sulfur to the atmosphere: the formation of seaspray aerosols, anaerobic respiration by sulfate-reducing bacteria and volcanic activity (relatively minor) (Figure 11.16c). Sulfur bacteria release reduced sulfur compounds, particularly H_2S, from waterlogged bog and marsh communities and from tidal mudflats. A reverse flow from the atmosphere involves oxidation of sulfur compounds to sulfate, which returns to earth as both wetfall and dryfall.

the sulfur cycle has an atmospheric phase and a lithospheric phase of similar magnitude

The weathering of rocks provides about half the sulfur draining off the land into rivers and lakes, the remainder coming from atmospheric sources. On its way to the ocean, a proportion of the available sulfur (mainly dissolved sulfate) is taken up by plants, passed along food chains and, via decomposition processes, becomes available again to plants. However, in comparison to phosphorus and nitrogen, a much smaller fraction of sulfur takes part in internal recycling in terrestrial and aquatic communities. Finally, there is a continuous loss of sulfur to ocean sediments.

11.6.5 The carbon cycle

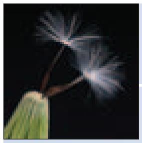
Photosynthesis and respiration are the two opposing processes that drive the global carbon cycle. It is predominantly a gaseous cycle, with carbon dioxide as the main vehicle of flux between atmosphere, hydrosphere and biota. Historically, the lithosphere played only a minor role; fossil fuels lay as dormant reservoirs of carbon until human intervention in recent centuries (Figure 11.16d).

Terrestrial plants use atmospheric carbon dioxide as their carbon source for photosynthesis, whereas aquatic plants use dissolved carbonates (i.e. carbon from the hydrosphere). The two subcycles are linked by exchanges of carbon dioxide between atmosphere and oceans. In addition, carbon finds its way into inland waters and oceans as bicarbonate resulting from weathering (carbonation) of calcium-rich rocks such as limestone and chalk. Respiration by plants, animals and microorganisms releases the carbon locked in photosynthetic products back to the atmospheric and hydrospheric carbon compartments.

the opposing forces of photosynthesis and respiration drive the global carbon cycle

11.6.6 Human impacts on biogeochemical cycles

It goes almost without saying that human activities contribute significant inputs of nutrients to ecosystems and disrupt local and global biogeochemical cycles. For example, the amounts of carbon dioxide and oxides of nitrogen and sulfur in the atmosphere have been increased by the burning of fossil fuels and by car exhausts, and the concentrations of nitrate and phosphate in stream water have been raised by agricultural practices and sewage disposal. These changes have far-reaching consequences, which will be discussed in Chapter 13.



Summary

SUMMARY

Patterns in primary productivity

Primary production on land is limited by a variety of factors – the quality and quantity of solar radiation, the availability of water, nitrogen and other key nutrients, and physical conditions, particularly temperature. Productive aquatic communities occur where, for one reason or another, nutrient concentrations are unusually high and the intensity of radiation is not limiting.

The fate of primary productivity

Secondary productivity by herbivores is approximately an order of magnitude less that the primary productivity on which it is based. Energy is lost at each feeding step because consumption efficiencies, assimilation efficiencies and production efficiencies are all less than 100%. The decomposer system processes much more of a community's energy and matter than the live consumer system. The energy pathways in the live consumer and decomposer systems are the same, with one critical exception – feces and dead bodies are lost to the grazer system (and enter the decomposer system), but feces and dead bodies from the decomposer system are simply sent back to the dead organic matter compartment at its base.

The process of decomposition

Decomposition results in complex, energy-rich molecules being broken down by their consumers