Environmental Cycles

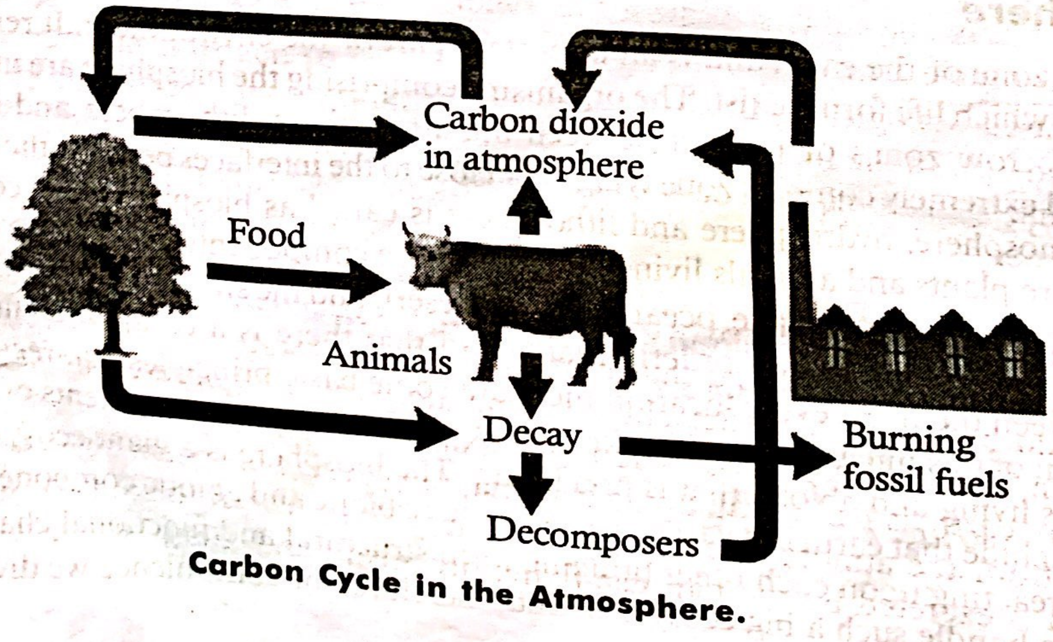
The flow of energy and cycling of minerals are the two important aspects of the biosphere. Both these are conducted by food chain. The cycles that control cycling of minerals are called biogeochemical cycles. The materials flow from living to non-living and back to the living through several cycles in the ecosystem. Green plants and decomposers play important roles in mineral cycling, as plants take up material from environment and decomposers return it back to environment, through air and water. The whole biosphere is a closed loop with interrelated environmental cycles. The major environmental cycles are carbon (C), nitrogen (N), sulfur (S), phosphorus, and oxygen cycles.

Carbon Cycle

The carbon being a basic constituent of all organic compounds and a major element involved in the fixation of energy by photosynthesis, is so closely tied to energy flow that the two are inseparable. The source of all the fixed carbon both in living organisms and fossil deposits is carbon dioxide CO_2, found in the atmosphere and dissolved in the waters of the earth. During photosynthesis, carbon from atmospheric CO_2 is incorporated into the production of the carbohydrate, glucose, $C_6H_{12}O_6$, that subsequently may be converted to other organic compounds such as polysaccharides (sucrose, starch, cellules, etc.) proteins and lipids. All the polymeric organic compounds containing carbon are stored in different plant-tissues as food and from them the carbon is passed on to the trophic levels of herbivores or phytoparasites, or retained by the plant until it serves as food for decay organisms (viz., decomposers). Some of the carbon is returned to the atmosphere (or the enveloping aqueous medium) in the form of CO_2 a by-product of plant respiration, in which, a considerable portion of glucose is oxidized to yield CO_2, H_2O and energy as follows:

$$1/6C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O + \text{Energy}$$

The CO_2 which is released as the by-product of plant respiration is again used by plants in photosynthesis. This is the basic carbon cycle which is simple and complete. Decomposing micro-organisms are important in breaking down dead material with the release of carbon back into the carbon cycle.



Carbon Cycle in the Atmosphere.

Similarly, carbon taken up by herbivores or phytoparasites may travel a number of routes. It may be incorporated into protoplasm (assimilation) and stored until the organism dies, where upon it is utilized by decomposers; it may be released through animal respiration; it may serve as live food for other organisms; or finally it may be stored in the environment as CO_2. Similar fates await carbon at the carnivore trophic levels. In fact, all the carbon of plants, herbivoures, carnivores and decomposers is not respired but some is fermented and some is stored. The carbon compounds that are lost to the food chain after fermentation, such as methane, are readily oxidized to carbon dioxide by inorganic reactions in the atmosphere. As for the storage of carbon in sediments, just as deposition works to store materials, erosion may uncover them, and inorganic chemical weathering of rock can oxidize the carbon contained there. Some carbon is permanently stored in sediments and not uncovered by weathering; it may be replaced by carbon dioxide released from volcanoes and other similar examples of intense geological activity. In modern age, man has greatly increased the rate at which carbon is passing from sedimentary form to carbon dioxide. The combustion of fossil facts is a significant means or recycling sedimentary carbon much faster than neutral weathering.

Small portion of carbon, especially in the sea, is found not as organically fixed carbon, but as carbonate ($CO_3=$), especially calcium carbonate ($CaCO_3$). $CaCO_3$ is very commonly used for shell construction by such animals as clams, oysters, some protozoa, and some algae. Carbon dioxide reacts with water to form carbonate in the following three step reaction :

$$CO_2 + H_2O \rightleftharpoons \underset{\text{Carbonic acid}}{H_2CO_3} \leftrightarrows \underset{\text{Bicarbonate}}{H^+ \; HCO_3^-} \leftrightarrows \underset{\text{Carbonate}}{2H^+ \; CO_3^=}$$

The presice amount of each of these constituents in the water depends on the pH of the water. Organisms such as clams can combine bicarbonate or carbonate with calcium dissolved in the water to produce calcium carbonate. After the death of the animal, this calcium carbonate may either dissolved or remain in sedimentary form.

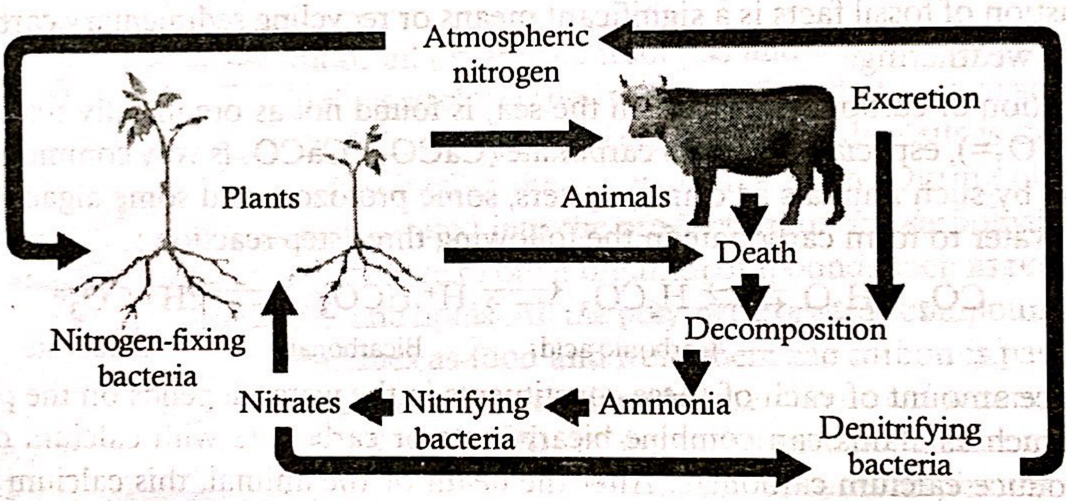
Nitrogen Cycle

Nitrogen is an essential constituent of different biologically significant organic molecules such as amino acids and proteins, pigments, nucleic acids and vitamins. It is also the major constituent of the atmosphere, comprising about 79 per cent of it. The paradox is that in its gaseous state, N_2 is abundant but is unavailable to most life. Before it can be utilized it must be converted to some chemically usable form.

To be used biologically, the free molecular nitrogen has to be fixed and fixation requires an input or energy. In the first step molecular nitrogen, N_2 has to be split into two atoms : $N_2 \rightarrow 2N$. The free nitrogen atoms then must be combined with hydrogen to form ammonia, with the release of some energy :

$$2N + 3H_2 \rightarrow 2NH_3$$

This fixation comes about in two ways. One is by high-energy fixation such as cosmic radiation, meteorite trails, and lightning that provide the high energy needed to combine nitrogen with oxygen and hydrogen of water. The resulting ammonia and nitrates are carried to the earth in rain water. The second method of nitrogen-fixation which contributes about 90 per cent of fixed nitrogen of earth, is biological. Some bacteria, fungi, and blue-green algae can extract molecular nitrogen from the atmosphere and combine it with hydrogen to form ammonia. Some of the ammonia is excreted by the nitrogen-fixing organism, and, thus, becomes directly available to other autotrophs. Some of these nitrogen-fixing organisms may be free-living, either in the soil (*e.g.*, bacteria – Azotobacter and Clostrudium) or in water (*e.g.*, blue-green algae – Nostoc, Calotherix and Anabaena) and produce vast quantities of fixed nitrogen. In other case, certain symbiotic bacteria of genus Rhizobium, although unable to fix atmospheric nitrogen themselves, can do this when in combination with cells either from the roots of legumes (*e.g.*, peas, beans, clover and alfalfa) and of other angiosperms such as Alnus, Ceanothus, Shepherdia, Elaeagnus and Myrica. The combination of symbiotic bacteria and host cells remains able to fix atmospheric nitrogen and for this reason legumes are often planted to restore soil fertility by increasing the content of fixed nitrogen. Nodule bacteria may fix as much as 50 to 100 kilo, grams of nitrogen per acre per year, and free soil bacteria as much as 12 Kilograms per acre per year. Further both free soil bacteria (Azotobacter and Clostridium) produce ammonia as the first stable product and like the symbiotic bacteria, they require molybdenum as an activator and are inhibited by an accumulation of nitrates and ammonia in soil.



Nitrogen Cycle in the Atmosphere.

Another source of nitrogen is organic matter. The nitrogenous wastes and carrion of animals are degraded by the detritus organisms, nitrogen is converted to the amino form (*e.g.*, L-Alanine). The amino group ($-NH_2$) is liberated from organic molecules to form ammonia; this process is called deamination. Certain specific bacteria, most notably of the genus Nitrosomonas, can oxidize ammonia to nitrite (NO_2) by the reaction.

$$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 2H^+$$

This reaction takes place in the soil, in lake or sea water or sediments, and whenever ammonia is being released and oxygen is present. As fast as nitrite is produced, other bacteria, such as Nitrobacter, can combine nitrite with oxygen to form nitrate (NO_3) by the reaction :

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

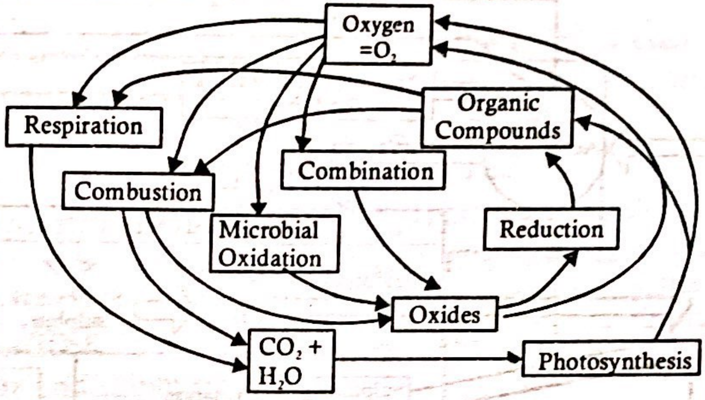
Both of these reactions which are performed by two nitrifying bacteria – Nitrosomonas and Nitrobacter are the parts of a single biological process called nitrification. In nitrification process, thus, ammonia is oxidized to nitrate and nitrite yielding energy. This energy is used by the bacteria to make their organic materials directly from carbon dioxide and water. Nitrate can be taken up by autotrophs at the beginning of food chain.

Degradation of nitrate is called denitrification, and may be important when oxygen concentration is low denitrifying bacteria such as pseudomonas can use the energy of the nitration to drive then metabolism and in so doing, they break the nitrate down to nitrite down to nitrite, ammonia, or molecular nitrogen.

Oxygen Cycle

Oxygen is a compound of several organic compounds and also required by organisms respiring aerobically.

Main sources. In nature oxygen occurs in the gaseous form constituting 20% if the total atmosphere. In the combined form it is found in CO_2, water and a number of oxidised salts.



Oxygen Cycle.

Use and Release. Land organisms take their requirement of oxygen for respiration directly from atmosphere. Aquatic forms do so from the diffused gas found in water. Some aquatic animals, however, come to the surface for getting oxygen directly from air. During respiration carbohydrate food is oxidised to form carbon dioxide and water. Combustion or burning of wood, coal, petroleum and natural gas also yield carbon dioxide, water, sulphur dioxide, nitrogen oxides, etc. Microbial oxidation form another pool of oxides. The oxides are reduced both chemically as well as biologically to release oxygen. Major replenishment of oxygen occurs through photosynthesis where water is split up in the process of photolysis. Because of it oxygen content of the atmosphere has largely remained constant for the last several million of years. Of course, in the beginning our planet did not possess free oxygen in its atmosphere. It accumulated there when photoautotrophs evolved.

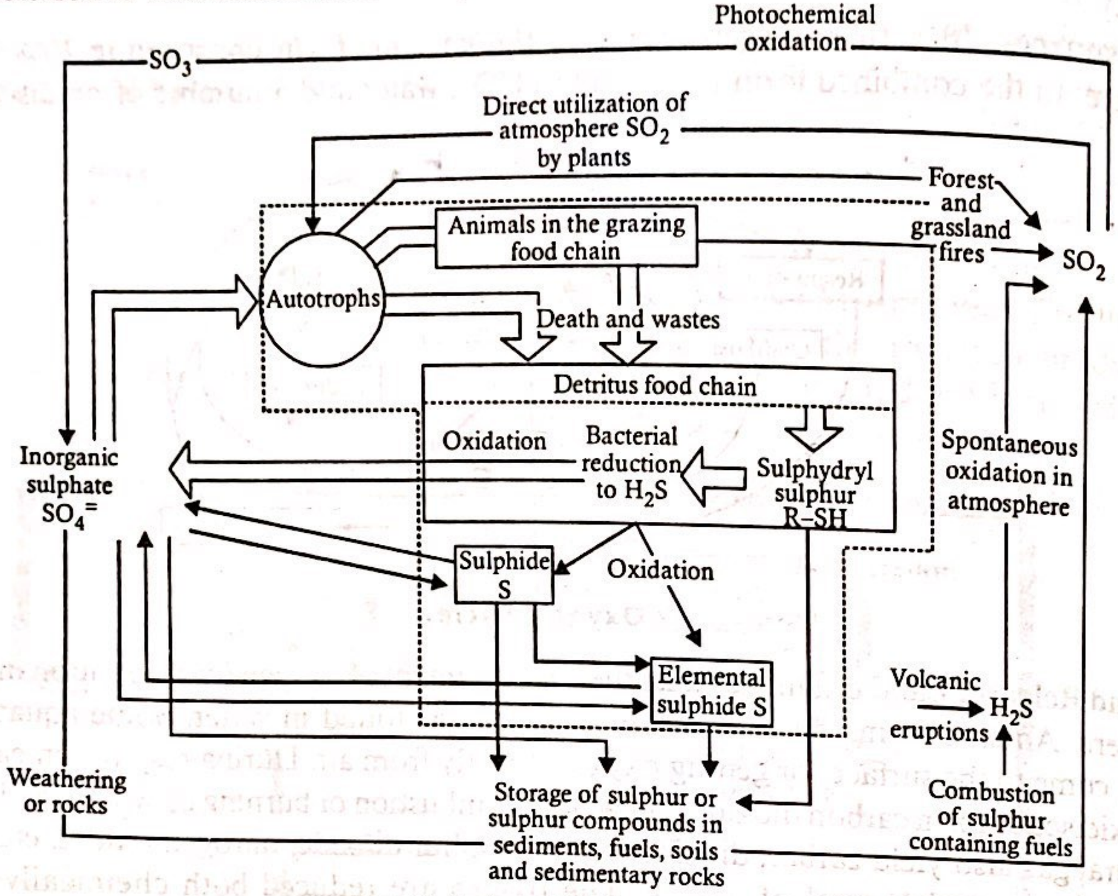
Sulphur Cycle

Sulphur, like nitrogen, is an essential part of protein and amino acids and is characteristic of organic compounds. It exists in a number of states-elemental sulphur, S, sulphides, sulphur monoxide, sulphite and sulphates. Of these three are important in nature : elemental sulphur, sulphides and sulphates.

The sulphur cycle is both sedimentary and gaseous. The sedimentary phase of sulphur cycle is long-termed and in it sulphur is tied up in organic and inorganic deposits. From these deposits, it is released by weathering and decomposition, and is carried to terrestrial and aquatic ecosystems in a salt solution. Atmospheric (gaseous) phase of sulphur-cycle is less pronounced and it permits circulation on a global scale.

Sulphur enters the atmosphere from several sources–the combustion of fossil fuels, volcanic eruption, the surface of the oceans and gases released by decomposition. Initially sulphur enters the atmosphere as hydrogen sulphide, H_2S, which quickly oxidizes into another volatile form, sulphur dioxide SO_2. Atmospheric sulphur dioxide, soluble in water, is carried back to earth in rainwater as weak sulphuric acid, H_2SO_4. Whatever it source, sulphur in a soluble form, mostly as sulphate

(SO_4^-) is absorbed through plant roots, where it is incorporated into certain organic molecules, such as some amino acids (*e.g.* cystine) and proteins. From the producers the sulphur in amino acids is transferred to the consumer animals, with excess being excreted in the faeces.



Sulphur Cycle.

Excretion and death carry sulphur in living material back to the soil and to the bottoms of ponds, lakes, and seas where the organic material is acted upon by bacteria of detritus food chain. Within the detritus food chain, the sulphydryl group (–SH) of amino acids (*e.g.* L–cysteine) is separated from the rest of the molecule as hydrogen sulphide (H_2S) by most decomposing bacteria as a normal part of the degradation of proteins. In an aerobic environment, the hydrogen sulphide is oxidized to sulphate by bacteria specially adapted to perform this conversion :

$$H_2S + 2O_2 \rightarrow SO_4^- + 2H^+$$

The sulphate produced then can be reused by the autotrophs. In anaerobic environments, such as bottom of certain lakes, it is impossible to oxidize sulphide by this means, because the process of oxidation requires oxygen. But if infrared radiation is present in these environments, there are photosynthetic bacteria that can use it to manufacture carbohydrates and oxidize sulphide either to elemental sulphur or to sulphate :

$$6CO_2 + 12H_2S + hv \rightarrow C_6H_{12}O_6 + 6H_2O + 12S$$

$$6CO_2 + 12H_2 + 3H_2 + hv \rightarrow C_6H_{12}O_6 + 6H_2O + 3SO_4^- + 6H^+$$

Elemental sulphur can also be utilized by other bacteria to form sulphate. If oxygen is present, the reaction is quite rapid.

$$2S + 3O_2 + 2H_2O \rightarrow 2SO_4^- + 4H^+$$

Under anaerobic conditions, elemental sulphur can still be oxidized to sulphate by certain bacteria if nitrate is present :

$$6NO_3^- + 5S + 2CaCO_4 \rightarrow 3SO_3^- + 2\ CaSO_4 + 2CO_3 + 3N_3$$

None of these bacterial reactions is unidirectional under certain conditions, sulphate can also be reduced either to sulphide or to elemental sulphur by bacteria. This series of reactions operating within the organic phase of the sulphur cycle provides a rather finely tuned mechanism for regulating the availability of sulphur to autotrophs.

The sulphur is removed from the organic phase in the form of elemental sulphur which is insoluble and accumulates in sediments. If iron is present in the sediment, it can combine with sulphide to form iron sulphides, all of which are highly insoluble :

$$Fe^{++} + S^- \rightarrow FeS$$

$$Fe(\text{ionic}) + 2S\ (\text{ionic}) \rightarrow FeS_2\ (\text{Ferrous sulphide or pyrite})$$

FeS_2 is highly insoluble under neutral and alkaline conditions and is firmly held in mud and wet soil. Some ferrous sulphide is contained in sedimentary rocks overlying coal deposits. Exposed to the air in deep and surface mining, the ferrous sulphide oxidizes and in the presence of water produces ferrous sulphate and sulphuric acid :

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$$

$$12FeSO_4 + 3O_2 + 6H_2O \rightarrow 4Fe_2\ (SO_4) + 4Fe\ (OH_3)\downarrow$$

In this manner sulphur in pyrite rocks, suddenly exposed to weathering by man, discharges heavy slugs of sulphur, sulphur acid, ferric sulphate and ferrous hydroxide into aquatic ecosystems. These compounds destroy aquatic life and cause acidic water.

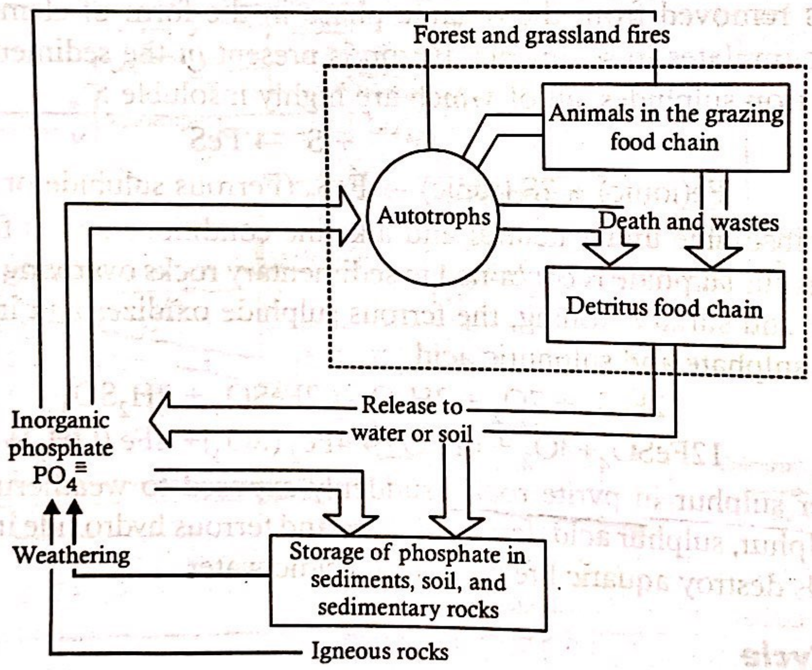
Phosphorus Cycle

Phosphorus cycle has no atmospheric phase. It occurs naturally in environment as phosphate (PO_4^-, or one of its analogues, HPO_4^- or $H_2PO_4^-$), either as soluble inorganic phosphate ions, as soluble organic phosphate (*i.e.*, as a part of a soluble organic molecule), as particulate phosphate (i.e. as part of an insoluble organic or inorganic molecules) or as mineral phosphate (*i.e.* as part of a mineral grain as found in a rock or sediment). The ultimate source of phosphate in the ecosystem is crystalline rocks. As these are eroded and weathered, phosphate is made available to living organisms, generally as ionic phosphate. This is introduced into autotrophic plants through their roots, where it is incorporated into living tissues. From autotrophs, it is passed along the grazing food chain in the same fashion as nitrogen and sulphur, with excess phosphate being excreted in the faces. An extreme example of faecal phosphate is the tremendous guano deposits built up by birds on the desert west coast of South America. Phosphates can also be released as particulate matter from forest and grassland fires.

In the detritus food chain, as large organic molecules containing phosphate are degraded, the phosphate is liberated as inorganic ion phosphate. In this from it can be immediately taken up by autotrophs, or it can be incorporated into a sediment particle, either in the soil of a terrestrial ecosystem or in a sediment of an aquatic ecosystem. The sedimentary phase of phosphorous cycle remains comparatively slow than the organic phase.

Besides phosphorus, there are biogeochemical cycles for all the other nutrients (minerals) used by living organisms, as well as some that are not. Most of them has complete cycles in sedimentary phase. The availability depends on their solubility in water and availability of water as solvent.

Thus, the geochemical cycles of different chemical substances are closed : the atoms are used over and over again. To keep the cycles going does not require new matter but it does require energy, for the energy cycle is not a closed one. Further the patterns of flow, both of energy and of chemical substances, are of great significance. The simpler patterns involve energy, as the source of energy are external to the ecosystem, and flow is unidirectional through it. Chemical substances, on the other hand, are finite and have their origin inside the ecosystem, thus they must continuously cycle within the system.



Phosphorus Cycle.