UNIT 4 NON-LIVING AND LIVING COMPONENTS OF ENVIRONMENT

Structure

4.1 INTRODUCTION

In the preceding units of this block we have studied the physical nature of the environment and different types of ecosystems. To understand the functioning of an ecosystem, it is essential to know about the nature and role of different living and non-living components of the environment. If we examine a particular ecosystem, say a forest, a grassland, a pond or a desert, we begin to see that none of the organisms living in it exist in isolation. Rather, each one is in a number of relationships, both with other organisms and with factors in the non-living environment. These interrelationships have two consequences:

- Flow of energy, and
- Cycling of nutrient materials.

Energy circuit in an ecosystem starts with solar energy that is absorbed and fixed by green plants. Its flow through different trophic levels and the final loss as heat into space are governed by the two laws of thermodynamics. Study of energy flow and the laws governing it will eventually help us in understanding the key role of energy in the functioning of the ecosystem.

Material cycles known as biogeochemical cycles explain how certain basic elements enter the biotic systems and after the death and decay of organisms return to the soil and the atmosphere. Functioning of the ecosystem depends on the flow of energy and cycling of materials which ensure stability of the system and continuity of life. These two ecological processes may be considered as the 'heart' of ecosystem functioning.

Ecosystem functioning is the result of interaction between non-living and living components. Further, interaction between different biotic components of an ecosystem affects its growth and stability. In this unit we will examine in detail the relationships among organisms of same species—intraspecific relations and among organisms of different species—interspecific relations which may be beneficial or harmful to one another. A study of these interrelationships at population and community levels will help to keep in mind that interdependence of all living things is the essence of ecosystem stability.

Objectives

After studying this unit you should be able to:

- give reasons for concepts of energy and matter being central to ecosystem, and define energy, and laws of thermodynamics,
- describe various biogeochemical cycle, and the role of micro-organisms in biogeochemical cycles,
- define niche and habitat,
- list and explain the factors that regulate growth of population,
- define, explain and use the concept of carrying capacity, and
- differentiate between intraspecific and interspecific relationships and explain how the population is governed by them.

4.2 ENERGY IN ECOSYSTEM

As you know, energy used for all life processes is derived from solar energy. It is absorbed by green plants during photosynthesis. The chemical energy thus fixed is then passed from producers to consumers. In respiration, part of this fixed energy is utilised for the growth and development of living beings. A large part of it, however, is lost as heat in several steps, and cannot be reutilised. This continuous flow of energy from the sun through various organisms to outer space maintains the life on the earth.

Trapping and flow of energy involves circulation of nutrient materials. These include the basic inorganic elements such as, carbon, hydrogen, oxygen and nitrogen. Besides, sodium, calcium, and potassium occur in small amounts. In addition, compounds such as; water, carbonates, phosphates and a few others also form part of living organisms. To run an ecosystem, it is essential that there be a continuous flow of these substances. These materials thus keep on cycling. They enter the biotic systems and after the death and decay of the organism return to the soil and the atmosphere.

4.2.1 Laws Governing Energy Flow

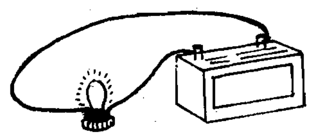
The term 'energy' is quite familiar to us and we use it in a very general sense. Often this usage does not correspond to the precise scientific definition. It is, therefore, important to first define it precisely.

Energy is defined as the capacity to do work. We use energy to cook food. We need energy to raise our feet, a truck climbs up a hill when energy is supplied to it from combustion of diesel oil and a light bulb glows when electric energy is supplied to it (Fig. 4.1). The developing countries of the Third World face perpetual energy shortage, and in the present day world, energy and prosperity go hand in hand.

As such, sun is the ultimate source of all our energy which caters to the need of our ecosystem. In the interior of the sun, a thermonuclear reaction is continuously going on at a temperature of about 10^8 K wherein hydrogen is converted into helium. This is accompanied by a release of huge amount of energy which manifests itself as heat and light.

K stands for kelvin which is a unit of temperature. If t is the temperature in 0°C then the corresponding temperature T in k is given by T = t+273.

Observations made from artificial satellites indicate that nearly 30% of the total solar radiation entering our atmosphere is reflected by the earth-atmosphere system. The remaining 70% of the radiation is absorbed by the earth's atmosphere. Of this 19% is absorbed directly by the atmosphere and the rest by the earth's surface. The blue and red components (400-500



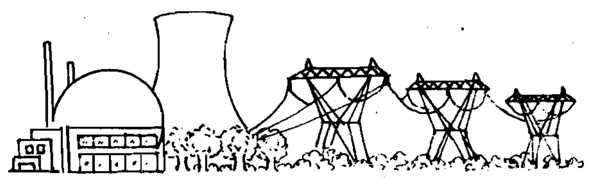


Fig. 4.1: Forms of energy.

nm and 600-700 nm band respectively) of solar radiation are strongly absorbed by chlorophyll, the green pigment, present in vegetation and are converted into chemical energy. That is how energy for the ecosystem is trapped.

The energy captured by the autotrophs will never revert back to the sun. Similarly, the energy which passes to the herbivore does not revert back to autotrophs and so on. **Thus, the flow of solar energy is unidirectional.** Its immediate implication is that an ecosystem would collapse if the sun stops giving out energy.

The second important fact is that at each trophic level energy content decreases progressively. This factor is easily explained by noting that the trapped solar energy is used up in metabolic activity and measured as respiration.

In an ecosystem energy is transferred in an orderly sequence. We have explained above that energy is always unidirectional. In a chain of events some useful energy may be lost as heat. Two descriptive physical laws apply to such situations. These are the **first** and the **second laws of thermodynamics**.

The first laws of thermodynamics deals with the conservation of matter and energy and states that energy cannot be created or destroyed but can only change from one form to another. For example, the energy of visible light is absorbed by green plants through photosynthesis; it is changed into chemical energy stored in the glucose molecules. Almost all living organisms including plants consume glucose in respiration and use the stored chemical energy for their metabolic activity. Some of the energy is dissipated as heat, another form of energy.

The second law of thermodynamics states that some useful energy is converted into unusable waste heat during every energy transformation. This heat energy escapes into the surrounding environment. Another way of saying the same thing would be that in every energy transformation, some energy is always lost in the form of heat that is thereafter unavailable to do further useful work (Fig. 4.2). For example, if we have to push an object on the floor some of the work which we are putting in pushing the object is used up as heat energy due to friction.

Much of the modern civilisation is built around the internal combustion engine and the incandescent light, which, respectively, waste 90% and 95% of their initial energy input. As oil and other non-renewable energy sources are becoming scarce and expensive it is imperative to reduce such unnecessary energy losses.

In the same way when energy stored in the body is used in doing some work, some of the useful energy is lost as body heat. In other words, energy transformation in the physical as well as biological worlds are less than one hundred per cent efficient, because energy's natural and unavoidable tendency is to spread out, i.e., become disorganised or disordered. The degree of disorder that occurs in any given system can be measured and expressed mathematically as **entropy**. In fact, the universe as a whole is tending towards a state of maximum entropy. In order to continue to function, organisms must continue to receive new input of energy in the ecosystem.

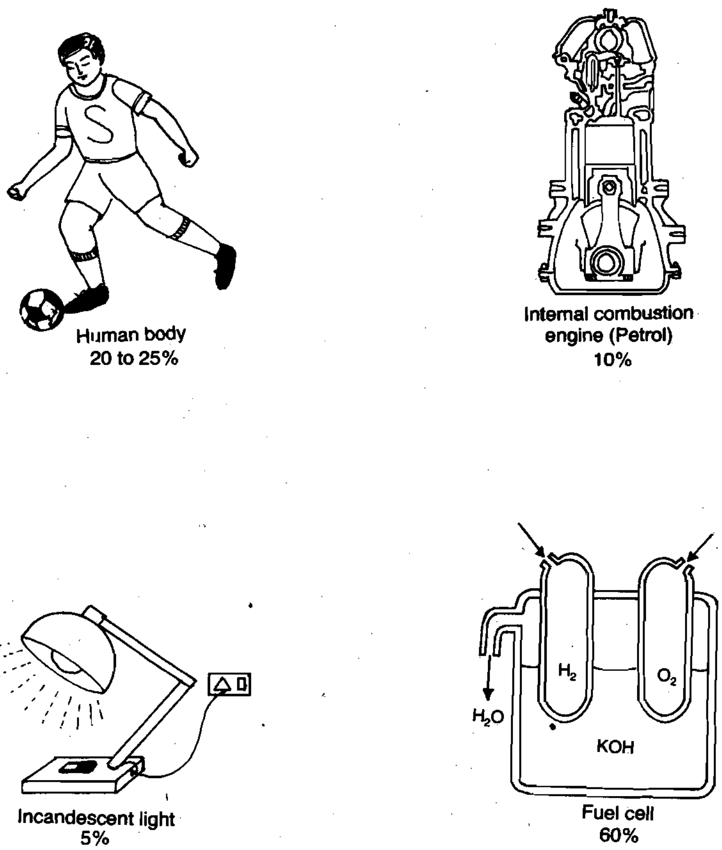


Fig. 4.2: Energy efficiencies of some common energy conversion devices.

4.2.2 Flow of Energy

Flow of energy through the ecosystem is a fundamental process which can be easily quantified if the energy input to the ecosystem and its subsequent transformation from one trophic level to another can be expressed in terms of calories.

Study of ecosystem energetics gives a sound basis for energy budget at individual, population and ecosystem level. We can get a scientific basis for evaluating efficiency of different trophic levels in an ecosystem and comparing diverse ecosystems by quantifying the energy flow.

One calorie (cal) is the amount of heat needed to raise the temperature of one cubic centimeter of water through one degree centigrade. One kilo calorie (kcal = 1000 cal)

The first step of energy flow is easiest to measure; that's why several studies are devoted to primary productivity. The incoming solar energy can be monitored with instruments such as a net radiometer which measures the total radiant energy; or a pyranometer/solarimeter which only measures the visible light energy. In aquatic ecosystems the primary production can be measured by following the changing oxygen or carbon dioxide levels in water.

At higher trophic levels measurement of energy flow involves determination of energy quantity for every species population in each trophic level, and then addition of these specific figures to give the overall energy flow for the trophic level. Because of the enormity of this job, investigation is often limited to studying the energy budget of a single species of animal in a community. The weight, food intake, faecal output and respiration of a few individuals are measured and their assimilation and production rates are calculated.

Human intervention in natural ecosystem is growing significantly. Human impact on the pattern and quantum of energy flow has changed significantly because of the considerable amounts of fossil fuel used by urban, industrial and rural communities.

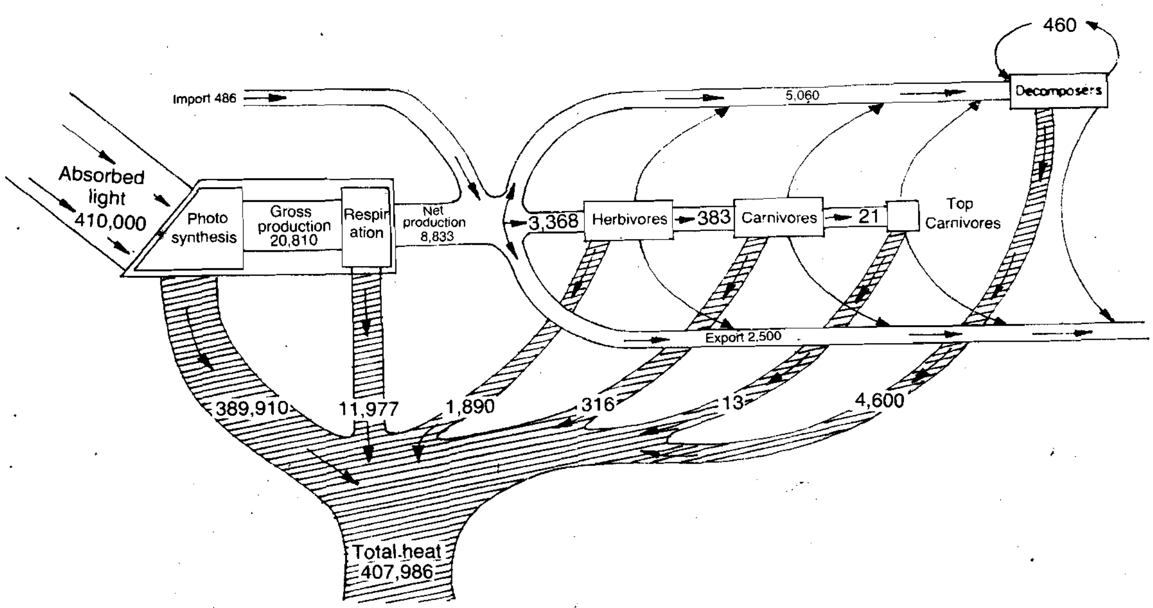


Fig. 4.3: Energy flow diagram for Silver Springs Florida. All figures are expressed as kilocalories of energy per square meter per year (After Odum, 1957).

Let us try to understand the energy flow diagram given in Figure 4.3. It provides a good idea of the pattern of energy flow studies conducted by Odum, a noted ecologist (1957) in Silver Springs, Florida. Most of the energy input is in the form of solar radiation. Waste heat dissipated from the system represents energy output. It is observed that the total energy input amounts to 410486 kcal/m^2/yr, (410,000 kcal/m^2/yr of solar energy and 486 kcal/m^2/yr in the form of organic matter imported into the system). It exactly matches the output of energy, 407986 kcal/m^2/yr is lost as waste heat and 2500 kcal/m^2/yr is exported from the system in the form of organic matter. Silver Springs Florida represent a balanced ecosystem in terms of ecological energetics. Thus energy enters the ecosystem as free solar energy and leaves it as heat, having undergone changes from a concentrated to a dispersed state. Studies of energy flow are very important in understanding ecosystem functioning and its rational management.

SAQ 1

a) Fill up the blank spaces in the following statements using appropriate words:

i) Fixed energy in the form of .... passes from autotrophs through .... to carnivores.

ii) The energy which passes to the .... does not revert back to ....

iii) Progressive decrease in energy occurs at each trophic level as a result of .... loss coupled with .... energy.

iv) The .... flow is one-way traffic and there is decrease in energy at each .... level as a result of respiratory loss.

b) Match the statement in Column A with the words given in Column B

A	B
i) Energy cannot be created or destroyed	a) entropy
ii) In any heat transfer some of the energy is released as less useful energy	b) 1st law of thermodynamics
iii) Energy tends to flow from a concentrated and ordered form to a more dispersed and disordered form	c) 2nd law of thermodynamics

4.3 MATTER IN ECOSYSTEM

Carbon, hydrogen, oxygen, nitrogen and phosphorus, as elements and compounds make up 97% of the mass of our bodies and more than 95% of the mass of all living organisms. Apart from these five, 15 to 25 other elements are needed in some form for the survival and good health of plants and animals. Some of these, are needed in relatively small or trace amounts. For example, phosphorus for the transformation of energy in cells; calcium for strengthening cell walls; potassium is indispensable for growth; iron, molybdenum and copper for the activity of certain enzymes and so on. These elements are taken up by producers in the ecosystem and get transformed into biomass. They are then utilised by different levels of consumers and finally, returned to the atmosphere and soil with the help of decomposers. Circulation of elements through air, water, soil, plants and animals takes place in biogeochemical cycles.

Biogeochemical cycles fall into two basic categories:

i) gaseous types where the reservoir is the atmosphere or the hydrosphere, and

ii) sedimentary types where the reservoir is the earth's crust.

Now we will discuss some of the important biogeochemical cycles.

4.3.1 Carbon Cycle

Carbon is present in the atmosphere, mainly in the form of carbon dioxide (Co_2). It is a minor constituent of the atmosphere (0.032%) as compared to oxygen (20.95%) and nitrogen (78.804%). However, without carbon dioxide life could not exist, for it is vital to the production of carbohydrates through photosynthesis by plants.

You have already learnt about the carbon cycle in the Foundation Course in Science and Technology Block 4, Unit 14. Carbon is returned to the environment about as fast as it is removed. Figure 4.4 illustrates the global carbon cycle. Carbon from the atmospheric pool moves to green plants, and then to animals. Finally, from them to bacteria, fungi and other microorganisms that return it to the atmosphere through decomposition of dead organic matter. Some dead plant and animal materials are buried in sediment before they can be broken down completely by decomposers. This process has been going on, to a greater or lesser extent, for hundreds of millions of years. It was important in the carboniferous period and much of plant and animal remains have been transformed into coal, oil and natural gas. When these fossil fuels are burned, the stored carbon finally enters the atmosphere in form of carbon dioxide. The carbon cycle is not so simple; in fact it is quite complicated. There are limited number of avenues by which carbon is utilized and a much larger number by which it is restored to the atmosphere. Collectively these various pathways constitute self-regulating feedback mechanisms resulting in a relatively homeostatic system. Some of the carbon is also returned to the atmosphere through respiration at various trophic levels in the food chain.

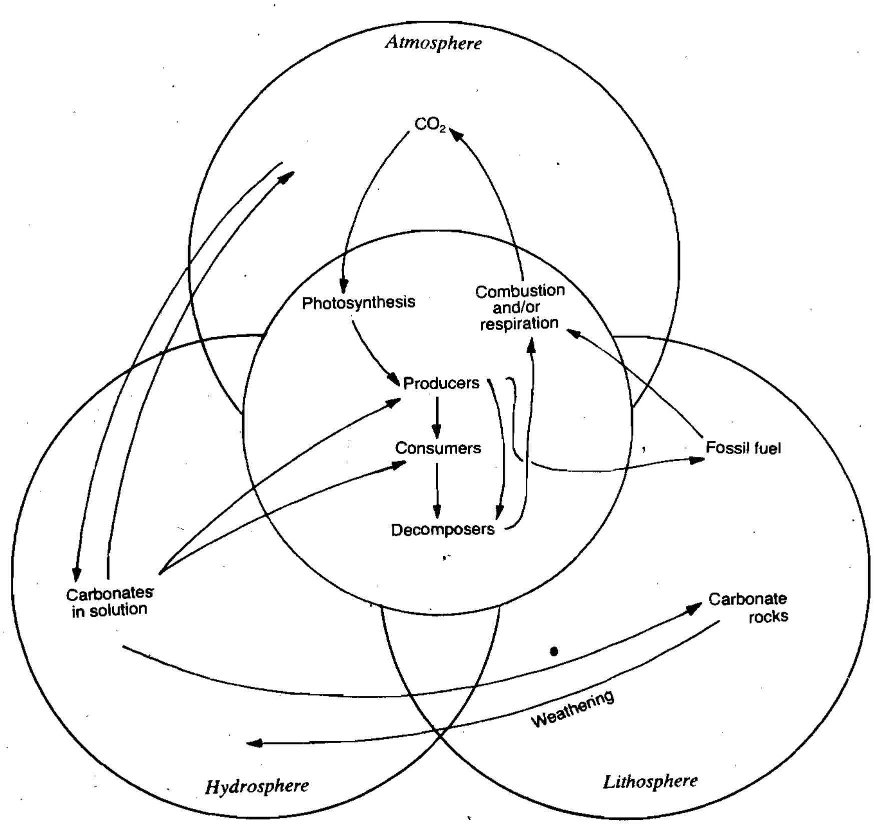


Fig. 4.4: Global carbon cycle.

It is estimated that half of the carbon fixed is subsequently returned to the soil in the form of decomposing organic matter. Before the onset of Industrial Revolution, flow of carbon among atmosphere, continents and oceans was balanced, but with the onset of industrialisation and urban development this equilibrium appears to have been disturbed.

The richest source of carbon today is the ocean, where it occurs in the form of carbonate and bicarbonate ions. The oceans contain about 50 times more CO_2 than the atmosphere. This regulates atmospheric CO_2 level to 0.032% despite photosynthetic uptake.

Thus, there is a continuous exchange of carbon dioxide between the atmosphere and organisms on one hand, and between the atmosphere and the sea, one the other. However, a major portion of the dissolved carbon dioxide in the ocean is below thermocline and so inaccessible for rapid exchange with the atmosphere. Thermocline is the layer of water where temperature drops abruptly. It separates the upper warmer layer from the deeper cooler water. The immediate source of carbon dioxide for exchange is thus restricted to relatively small quantities of carbon dioxide in the surface layers of water.

SAQ 2

Fill up the blanks in the following statements which describe carbon cycle :

It is a .... cycle. By volume .... CO_2 is approximately 0.032%. Carbon from the atmospheric pool moves to .... then to consumers, and finally from both of them to ....Some proportion of .... matter of green plants contributes to the .... of coal deposits, which as a result of .... return the .... to the atmosphere. The enhanced carbon dioxide results in the .... of atmospheric temperature. Major portion of the dissolved carbon dioxide in the oceans is below the........

4.3.2 Nitrogen Cycle

Nitrogen is an element essential for protein synthesis in all living organisms. It constitutes nearly 16% by weight of all the proteins. There is an inexhaustible supply of nitrogen in the atmosphere but the elemental form can not be used directly by most of the living organisms. Nitrogen needs to be '**fixed**', that is, coverted to ammonia, nitrites or nitrates, before it can be taken up by plants. Nitrogen fixation on earth is accomplished in three different ways : (i) by certain free-living and symbiotic bacteria and bluegreen algae (ii) by man using industrial processes (fertilizer factories) and (iii) to a limited extent by atmospheric phenomena such as thunder and lightning. At present, the amount fixed by man industrially far exceeds the amount fixed by biological and atmospheric actions.

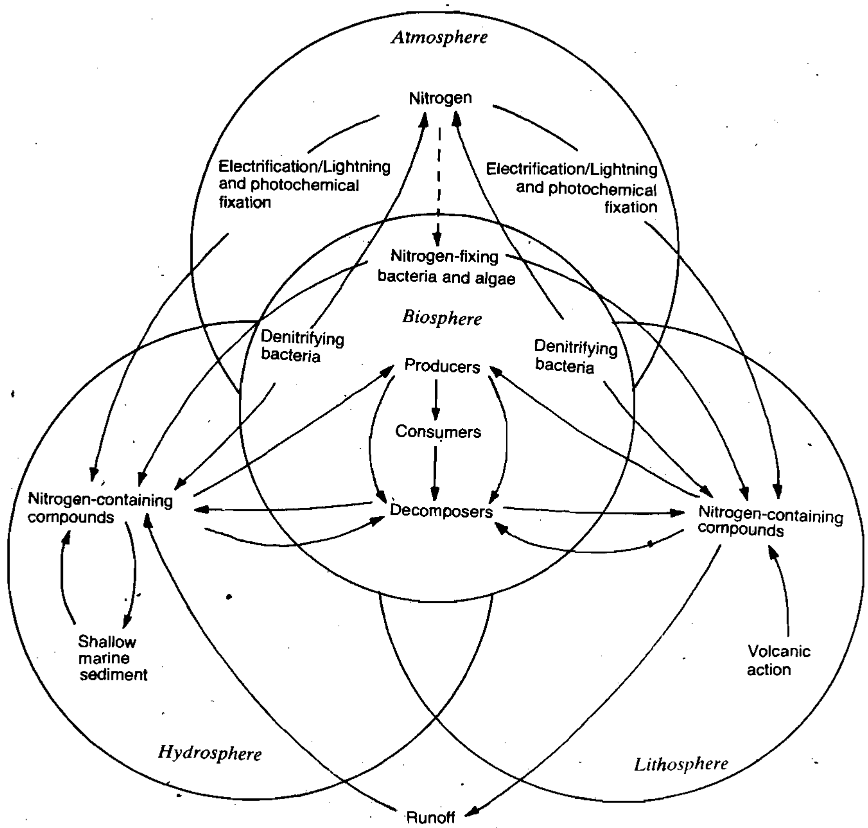


Fig. 4.5: Nitrogen Cycle. This diagram shows how nitrogen enters the biosphere through the action of algae and bacteria.

As you can see from Figure 4.5, nitrogen at any time is tied up in three different 'compartments' or 'pools'—the atmosphere, soil and water, and living organism. The periodic thunderstorms convert the gaseous nitrogen in the atmosphere to nitrates which eventually reach the earth's surface through precipitation and then into the soil to be utilized by plants. More importantly, however, are certain microorganisms capable of fixing atmospheric nitrogen. These include freeliving (e.g. *Azotobacter*) and symbiotic (e.g. *Rhizobium*) nitrifying bacteria and bluegreen algae (e.g. *Anabaena, Spirulina*). Ammonium ions can be directly taken up as a source of nitrogen by some plants, or are oxidized to nitrites or nitrates by specialized bacteria called *Nitrosomonas* and *Nitrobacter*, respectively.

The symbiotic bacteria capable of fixing atmospheric nitrogen, live in the root nodules of leguminous plants like peas, beans, alfalfa, clover, etc. Throughout the world these legume crops play an important role in enriching the soil with nitrogen in usable form. The traditional farmer has been aware of this fact and practices 'crop rotation', the practice of alternating legume crops with cereal crops.

The nitrates synthesised by bacteria in the soil are taken up by plants and go through higher trophic levels of the ecosystem. During excretion and upon the death of all organisms nitrogen is returned to the soil in the form of ammonia. Certain quantity of soil nitrates, being highly soluble in water, are lost to the system by being transported away by surface run-off or ground water. In the soil as well as oceans there are special denitrifying bacteria (e.g. *Pseudomonas*) which convert the nitrates/nitrites to elemental nitrogen. This escapes into the atmosphere, thus completing the cycle.

Agricultural scientists wish that our cereal plant species, rice, wheat, etc., had the ability, like the nitrifying bacteria, to fix atmospheric nitrogen directly, so we could dispense with the costly fertilizer applications which lead to soil and water pollution.

SAQ 3

In the following sets of statements, tick the correct and put a cross for the wrong ones:

a) Despite its immense value and indispensable nature, nitrogen is never taken up directly by animals and higher plants. This is because

   i) nitrogen is inert and does not participate in any reaction. [ ]

   ii) animals and plants have no mechanism to make use of atmospheric nitrogen. [ ]

b) Rhizobia are symbiotic microbes. This means that

   i) they obtain nutrition from other organisms. [ ]

   ii) they obtain nutrition from dead and decomposed organisms. [ ]

   iii) they are autotrophs. [ ]

   iv) they live in partnership with other organism. [ ]

c) The concentration of nitrogenous matter in soil will be greatest after growing a crop of

   (i) beans (ii) sugarbeet (iii) barley (iv) wheat (v) potatoes

   [ ] [ ] [ ] [ ] [ ]

4.3.3 Water Cycle

Water cycle is another important material cycle. Water is one of the important substances necessary for life. On an average water constitutes 70% of the body weight of an organism. It is an important ecological factor that determines the structure and function of the ecosystem. Cycling of all other elements is also dependent upon water as it provides the transportation to different compartments and is also a solvent medium for their uptake by organisms. It is needed along with carbon dioxide in photosynthesis and has moderating effect on the temperature of the surrounding areas by virtue of its heat absorbing ability.

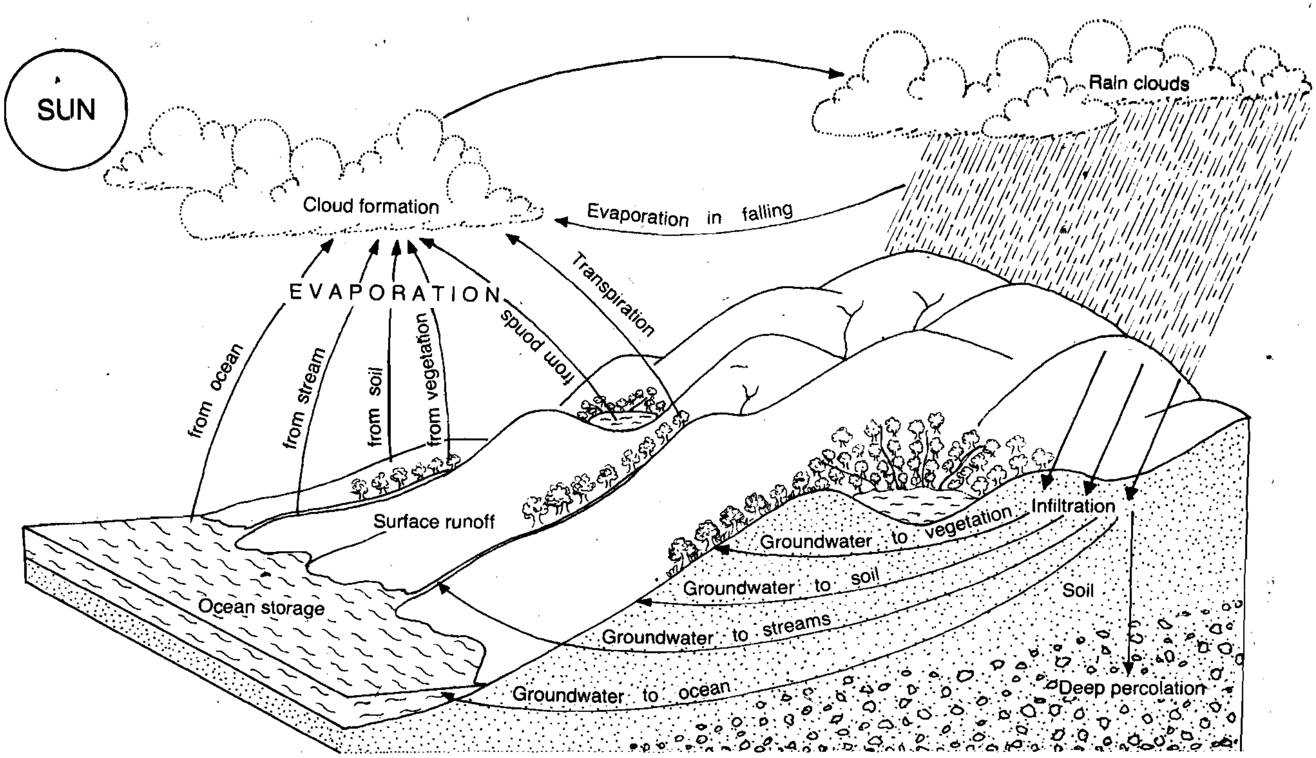


Fig 4.6: Simplified form of water cycle.

Protoplasm, the physical basis life, is made up of 85-90% water. Human blood, too, contains 90% water. However, significant amounts of water are incorporated by the ecosystem in protoplasm synthesis and a substantial return to the atmosphere occurs by way of transpiration from living plants and evaporation from animals.

Water covers about 75% of the earth's surface, occurring in lakes, rivers, seas and oceans. The oceans alone contain 97% of all the water on earth. Much of the remainder is frozen in the polar ice and glaciers. Less than 1% water is present in the form of ice-free fresh water in rivers, lakes, and aquifers. Yet this relatively negligible portion of the planet's water is crucially important to all forms of terrestrial and aquatic life. There is also underground supply of water. Soils near the surface also serve as reservoir for enormous quantities of water.

The earth's supply of water is stable and water is used over and over again. About one third of all solar energy is dissipated in driving the water cycle. Sunshine evaporates water from the oceans, lakes and streams, from the moist soil surfaces and from bodies of living organisms. Water vapour gathers in the form of clouds which move with the winds over the earth's surface. After cooling and condensation, water falls in the form of rain or snow. This constant movement of water from the earth into the atmosphere and back is known as the water cycle. Some of the water which falls on the land percolates through the soil until it reaches a zone of saturation. Below the zone of saturation is a solid rock through which water cannot percolate. The upper surface of this zone of saturation is known as the water table. The extra water runs off in the form of streams which converge and join to form rivers. Finally, water is returned to the ocean. Figure 4.6 shows some of the important steps of the water cycle. About 10×10^{20}g of water, which is nearly 0.004% of the total, is all the time moving in the cycle, rest of the earth's water is in cold storage.

SAQ 4

Fill up the blanks in the following statements about the water cycle:

Water covers .... % of the earth's surface. Only about .... Much of the water is in .... storage in form of .... and ....

4.3.4 Sedimentary Cycle

Phosphorus, calcium and magnesium are components of the sedimentary cycle. Sulphur is to some extent intermediate, since two of its compounds hydrogen sulphide and sulphur dioxide formed under some circumstance, add a gaseous component to its normally sedimentary cycle. The elements concerned in the sedimentary cycle normally do not cycle through thermosphere but follow a basic pattern of flow through erosion, sedimentation, mountain building, volcanic activity and biological transport e.g., through the excreta of marine birds. The sulphur cycle is a good example to illustrate the linkage between air, water and the earth's crust, and hence, a brief account of this cycle is given here.

Sulphur Cycle

Sulphur is found in gaseous forms like hydrogen sulphide and sulphur dioxide in the atmosphere, and as sulphates, sulphides and organic sulphur in the soil. The only known natural source of above gases in the atmosphere is volcanic emission. Nowadays, from burning of fossil fuels, sulphur is released in the atmosphere at a rate that is expected to equal the emission from natural sources by the year 2000 AD. Sulphur is an essential constituent of certain amino acids, and vitamins of the B-complex group. In figure 4.7 we show you the cycling of sulphur in the biosphere. Sulphur in the form of sulphates is incorporated in the proteins of autotroph tissues. It then passes through the grazing food chaining and excess of it is released through the faeces of animals. Within the detritus food chain the decomposition of proteins releases sulphur. Under aerobic conditions fungi like *Aspergillus* and *Neurospora* and under anaerobic conditions the bacteria like *Escherichia* and *Proteus* are largely responsible for the decomposition of proteins.

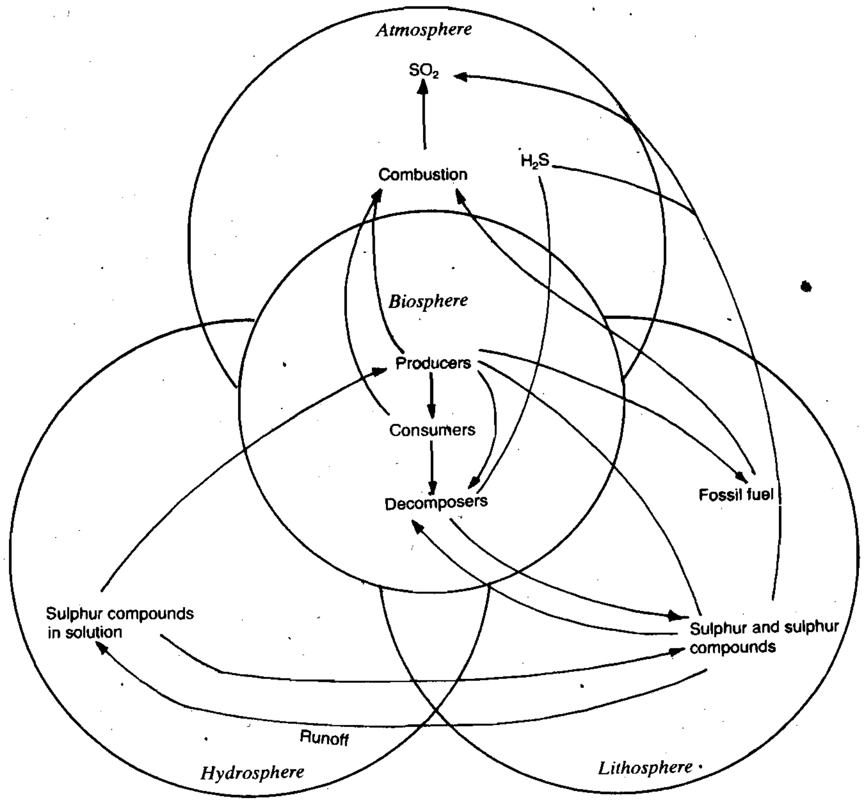


Fig. 4.7: Sulphur cycle. Bacteria are important factors in the cycle, changing sulphur into various forms in the soil.

In anaerobic soils and sediments hydrogen sulphide is formed by sulphate reducing bacteria like *Desulphoyibro desulfuricans*. Species of *Beggiatoa* oxidise hydrogen sulphide to elemental sulphur and species of *Thiobacillus* oxidise it to sulphate. There are also green and purple sulphur photosynthetic bacteria that oxidise hydrogen sulphide to elemental sulphur.

SAQ 5

More than one answer is given for a question, indicate the correct one in the box provided:

1) The principal form of sulphur that is reduced and incorporated into proteins by autotrophs is

   a) elemental sulphur b) sulphur dioxide

   c) sulphate d) hydrogen sulphide [ ]

2) A large quantity of sulphur, now a days, is thrown into the atmosphere from

   a) volcanic activities b) burning of vegetation

   c) burning of fossil fuel d) activity of microorganisms [ ]

Now that you have learnt how organisms depend on the environment for their energy and material requirements, we will examine the relationships between organisms of the same species and among organisms of different species. We will start at the population level, the level of interaction among members of the same species.

4.4 INTRASPECIFIC RELATIONS

The interactions between members of the same species are known as intraspecific relations and these are frequently very strong varying from open conflict to gregariousness. There are differences between species, of course. Some species, like moose, being quite solitary, have little association with others of their own species. While some animal populations exhibit varying degrees of social organisation. Many species exhibit territoriality,i.e., individuals compete for the 'rights' over some portions of their habitat. The winner uses the territory and the loser has to leave. The area in which an animal lives, eats and functions is known as its home range. Territories and home range vary in size. Territories may cover several miles in the case of large animals or birds or, may be limited to a single plant in the case of some insects. Territoriality serves to diminish destructive competition for resources such as food or habitat by limiting the number of organisms of a species in a given area.

Intraspecific relations are also expressed in patterns of hierarchy in species. The most familiar example is the 'pecking order' in chicken. At the top of the pecking order is the chicken that can dominate all others and is not dominated by any while feeding. In the middle are some chicken that are pecked by some and in turn peck others. At the bottom is the chicken that all other chicken can dominate and peck but which cannot peck any chicken. These dominant—subordinate relationships are more prominent when the choice for mates arises. Extreme social organisation is found in the structure of colonies of insects like termites, ants and bees.

Insect colonies may be so highly organised that individuals may not able to survive outside of the society. For example, bees in a hive are so organised in their functioning that a beehive looks more like an organism with cells rather than a population of individuals.

4.4.1 Population Growth when Resources are not Limited

Population growth can be determined by looking at factors that tend to increase the number of individuals in that population, like, birth and immigration and those factors that tend to decrease the number like, death and emigration (see Table 4.1).

Table 4.1: Population growth results from the net effect of all the factors given. These factors in turn are the result of species characteristics and environmental conditions

Factors	Increase in Population	Decrease in Population
1. Reproductive potential	high	low
2. Number of individuals capable of reproduction	large	small
3. Food	plenty	scarce
4. Habitat	space available	space not available
5. Climate	favourable	unfavourable
6. Immigration	high	low
7. Emigration	low	high
8. Disease	low	high
9. Predation	low	high

Let us imagine that we select a single bacterium and allow all its descendants to grow and reproduce without any restriction. In a month this bacterial colony would be larger than the visible universe and it would be expanding outwards at the speed of light. All populations have the potential for explosive growth under optimal growth conditions because nearly all mature individuals can produce offspring.

When births exceed the number of deaths, population increases. For example, suppose a population (N) has 1,000 individuals i.e. N = 1000, a birth rate (b) of 40 per year and a death rate (d) of 10 per year, the annual rate of natural increase (r) in that population would be

$$r = \frac{b - d}{N} = \frac{40 - 10}{1000} = .03 = 3\%$$

The rate of natural increase does not include any changes in the population size from either immigration or emigration which for the purpose of our discussion can be assumed to be equivalent. Populations with a positive rate of natural increase grow large each year. The expected increase (I) can be calculated by multiplying the rate of natural increase (r) by the current population size (N)

$$I = rN$$

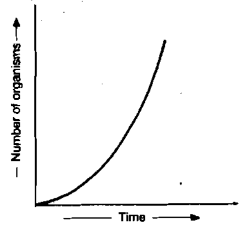


Fig. 4.8: The J-shaped curve of population growth of a species.

This formula indicates that population growth is exponential: If N is large at the end of each year, I will also be large. This means that population size increases by an ever larger amount each year under favourable conditions. When a graph is plotted for the population size, the resulting growth curve is J-shaped as shown in Figure 4.8. This type of exponential growth occurs only under conditions of unlimited resources. Except under a laboratory set-up, no population can expect to find resources unlimited for growth.

With unlimited resources and ideal environmental conditions, a species can produce offspring at the maximum rate. This is called its **biotic potential.** Species such as bacteria, insects and mice which can produce a large number of offspring in a short time have high biotic potentials. Larger species like elephants, tigers and humans that produce only a few offspring have a low biotic potential.

The exponential growth of human populations we have been witnessing in certain countries including India, does not mean that resources are unlimited, but that the remarkable advances made in medicine and technology have brought down human death rates considerably and alleviated to certain extent, various ill effects associated with crowding in nature, allowing exponential growth, albeit temporarily. You should also be aware of the fact that even under natural conditions, the early growth pattern could be exponential because at least initially the resources are abundant. You will learn more about human populations in Unit 5.

4.4.2 Population Growth when Resources are Limited

Given the finite nature of resources-chiefly food and space, a habitat can not support any population beyond a certain size. If the population grows beyond that limit, resource limitation shows it adverse effects on the population by increasing death rates and decreasing birth rates, which will lead to a decline in population density down to the limit set by available resources in the habitat. **The maximum number of individuals of a population that its environment can support and sustain is called the carrying capacity (K).** When the carrying capacity is reached, (N = K), r value will be zero in other words, birth rates equal death rates and the population should maintain a steady state equilibrium.

Population size is believed to level off at the carrying capacity (K) (Fig. 4.9) of the environment. In other words, the environment is capable of sustaining a population of a limited size. As the population increases in size, there will be more competition for the available space and food which in turn will affect population growth.

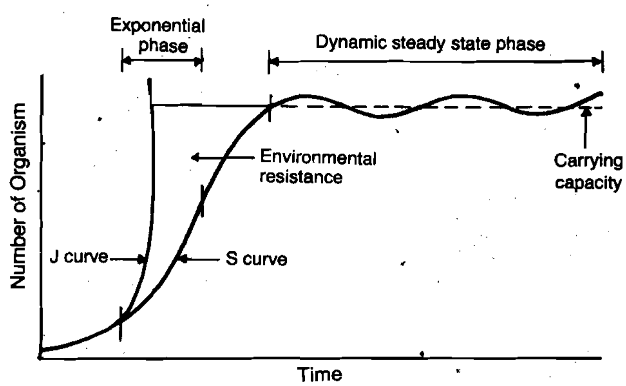


Fig. 4.9: The J-shaped curve is converted to an S-shaped curve when a population encounters environmental resistance and exceeds one or more limiting factors.

In nature, it is not as though the adverse effects of increasing numbers or crowding will manifest themselves only when the carrying capacity (K) is reached or exceeded; on the contrary, at any stage each extra individual added to the existing population reduces the per capita availability of resources by certain percentage. Let us consider an example to illustrate this point : assume that a population having an 'r' value of 0.25 is expanding in a habitat with a carrying capacity of 100. In this habitat, the total space, a vital resource for population growth, available is $100m^2$. The initial population of 20 individuals has

5 m^2/individual of space. After one year, the population size increase to 25 and now the available space is only 4m^2/individual. Thus, resources get less progressively with time, right from the beginnings,affecting both birth rates and death rates. This effect can be shown as the fraction $\frac{(K-N)}{K}$.

Insertion of the fraction into the exponential equation, makes it a logistic equation :

$$I = r\,\frac{(K-N)}{K}$$

This equation describes the pattern of population growth under resource limitation and when birth rates and death rates become density-dependent, i.e., birth rates decrease and death rates increase with increasing population density. When the population density is low (N is small) the value of $\frac{(K-N)}{K}$ is close to 1 and hence its effect on rN will be negligible. However, as N increases and approaches the carrying capacity (K), the value of the fraction gets smaller and its effect on rN (change in population size) is greater. When finally the environment is saturated (N = K), the expression $\frac{(K-N)}{K}$ has a value of zero, and makes rN $\frac{(K-N)}{K}$ zero, which means the population size does not change. If the population happens to overshoot the carrying capacity (N > K), we can expect it to decline since the expression $\frac{(K-N)}{K}$ has now a negative value. The logistic type of population growth yields a sigmoid, S-shaped curve.

All the limiting factors that reduce the growth rate of a population constitute **environmental resistance**. These factors include predation, competition for resources, food shortages, disease, adverse climatic conditions and unsuitable habitat. As a population faces environmental resistance the J-shaped curve is changed to an S shaped or sigmiod curve (Fig. 4.9).

SAQ 6

Which one of the graphs given below shows what has happened to the human population of the world over the last 50 years?

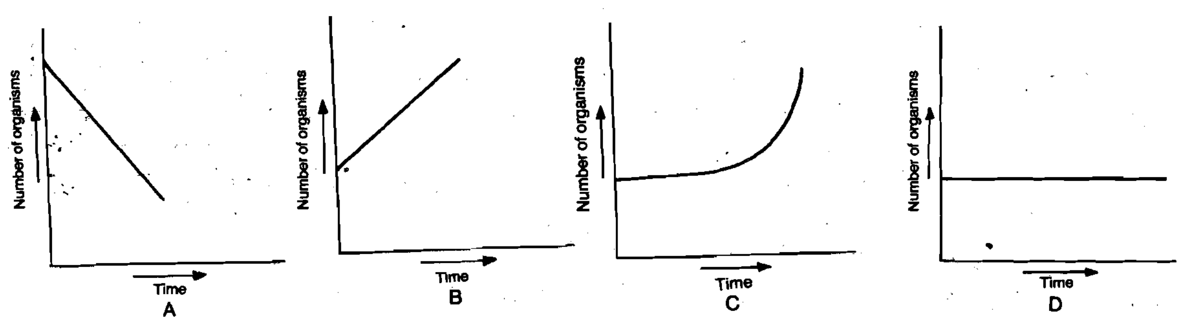


Figure A B C D

4.5 INTERSPECIFIC RELATIONS

The biological community is a complex network of interactions. These interactions take place not only among different individuals of the population of a species, but also among individuals of different species in a community, i.e. interspecific relations. Intraspecific interactions involve, among other things, competition for food, space and mates, and we have learnt about some consequences of such competition while considering logistic growth.

Interspecific relations, on the other hand, involve more complex interactions since the set of environmental factors influencing each of the interacting species are often so different. The relation may be direct and close as between a tiger and deer, or indirect and remote as between an elephant and a beetle. In the latter case, the interaction, if any, is only through a chain of species links. Specific terms are applied to species interactions depending upon whether the interaction is beneficial, harmful or neutral. Following the ecologist Odum, we can see all kinds of interaction possible by designating '±' for beneficial, '∓' for harmful and 'O' for neutral.

Species A	Species B	Name of interaction
+	+	– Mutualism
O	O	– Neutralism
+	O	– Commensalism
+	–	– Predation, Parasitism
–	–	– Competition
O	–	– Amensalism

For example, mutualism is an interaction in which both the interacting species benefit (+, +). Mutualism appears to be more common in nature than was thought to be.

The most familiar example of mutualism is pollination in which the plant benefits by getting cross pollination accomplished by the bee and the bee benefits from the nector that the plant offers in return. Another example is the association between ants and certain species of Acacia tree. The tree provides a safe and secure habitat for ants to set up their colony, and the ants in return protect the host tree from insects and small hebivorous animals that would otherwise eat away all the leaves. One can say that the relation between man and domesticated plants and animals is also a case of mutualism. These species, which would not normally survive competition with their wild cousins in nature, are ensured continued reproduction by efforts of man who in turn can not survive without them.

Commensalism is an interaction in which only one species benefits and the other is unaffected (+, O). The epiphytic orchid plant growing on the branches of a mango tree is a common example of commensalism, the mango tree derives no benefit. In nature, the most important interactions to be observed are competition, parasitism and predation. These are also of great relevance to man as we shall learn later in this unit.

4.5.1 Competition

We are all familiar with the process of competition as we ourselves face it in various ways in our day-to-day life. Competition occurs in nature generally, but not necessarily, when resources like food, space, mates are limited. Resource limitation leading to competition is implicit in Darwin's ideas on struggle for existence and survival of the fittest. Though not widely recognised competition could occur even when resources are not limiting. For example, consider species A that does not require a certain resource for its existence, but it prevents species B from acquiring that resource which the latter needs. The consequence is that the growth and reproduction of species B are reduced because of the presence of species A in the same habitat. This is called ' interference competition' and appears to be rather common among the higher animal groups. Although competition is most intense when the competing species are closely related, because their requirements are similar, competition between taxonomically unrelated species is not uncommon. For instance, in certain South American lakes, shore birds such as flamingoes compete with fish in the lake for a common resource—lake zooplankton which serves as food for both fish and birds. It has been observed that in lakes with large resident populations of flamingoes, fish populations are comparatively small.

What happens when two related species compete for the same resource needed by both? The outcome usually depends on how 'competitive' the species are. If one species is competitively superior, it will eventually exclude the other species from the habitat,a phenomenon referred to as **Gause's Principle of Competitive Exclusion**, named after the Soviet biologist G.F. Gause. If both are equally strong competitors, the outcome depends on the initial conditions, an uncertain and unstable coexistence is possible. If however, both species are weak competitors, both could co-exist peacefully indefinitely in the same habitat.

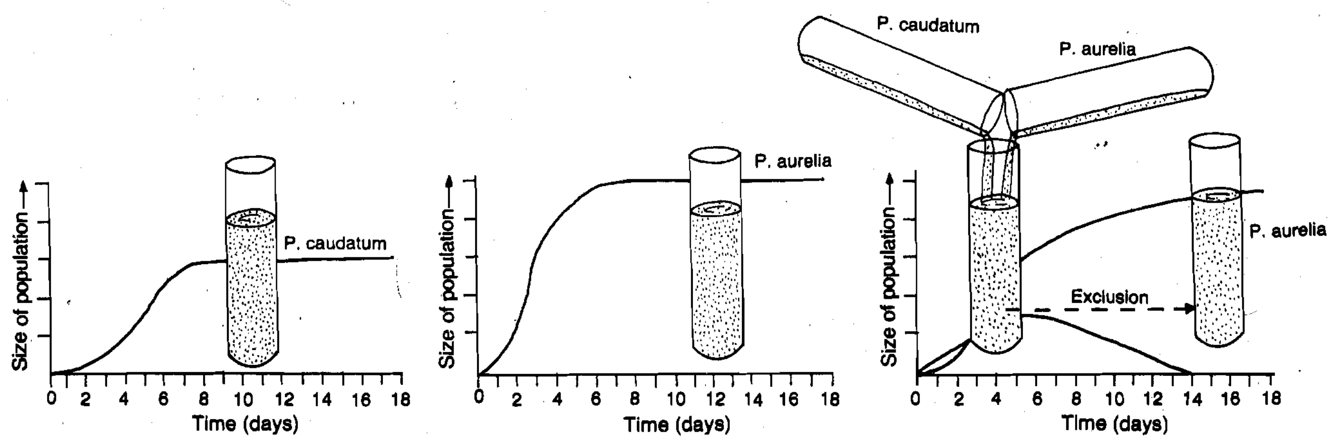


Fig. 4.10: Gause's Competitive Exclusion Principle. When two species of Paramecium (A) and (B) are grown in the same culture (C), one species (B) predominates and the other (A) declines.

Experiments conducted by many ecologists under laboratory conditions demonstrate the competitive exclusion of the weaker competing species. Gause showed this using two species of the familiar microorganism *Paramecium.* When *P.caudatum* and *P. auraelia* are cultured together, the former is eventually eliminated (Fig. 4.10). Do such experiments prove that competition and competitive exclusion occur regularly in nature ? In general, the evidence for competitive exclusion, if any, in nature is rather circumstantial. Because the conditions in nature are much more complex than in a laboratory, the outcome of competition between the two species of *Paramecium* could be entirely different from what Gause found in the laboratory. Nevertheless, there are a few recorded cases of competitive exclusion in nature. For example, the disappearance of the native red squirrel from England was believed to be due to its replacement by the American grey squirrel which was introduced earlier in England. Even in this case, the evidence is still only circumstantial.

While reverse competition at the intraspecific level might lead to population regulation, establishment of social hiearchy "peck order" and territoriality, at the interspecific level competition may lead to extinction of the inferior species, narrow specialization to avoid competition, and to evolution of new species.

4.5.2 Niche

Gause's competitive exclusion principle states that two species having identical requirements can not occupy the same '**niche**' indefinitely. This brings us to the question—what is a niche? A species niche is its unique functional role or place in an ecosystem. It is a description of all the biological, physical and chemical factors that a species needs to survive, stay healthy and reproduce.

To describe a species ecological niche one must know where it lives—**habitat niche**; the species it eats or decomposes, what species it competes with—its **food niche**; how and when it reproduces—its **reproductive niche** and its temperature shade, slope humidity and other requirements i.e. its **physical** and **chemical niche**.

A common analogy is that an organism's habitat which is part of its niche is its 'address' in an ecosystem. Its ecological niche is its 'occupation'. Information about ecological niches helps people to manage species as a source of food and to predict the result of either removing or adding species from or to an ecosystem.

A niche is something unique for a species, which means no two species have exactly identical niches. We can readily accept the fact that the niches of two species of Crab - one living in soft mud and the other in sandy burrows, are quite different, but it is not easy to understand how the niches of two crab species, both living in similar sand burrows could be different. Ecologists consider niche as a species-specific attribute, defined not just by its habitat but by all the parameters that are of relevance to the organism. For instance in the example above, the niche of the sandy burrow crab species might be defined by the coarseness of the sand it prefers, amount of moisture it needs, the level of dissolved oxygen it can tolerate, the size of food organisms it can capture, the time of day it is active, and so on. Now you can see that a difference in just one of these parameters is enough to render the niches different. Thus, all the parameters being identical, if one crab species feeds during daytime and the other species at night, their niches would be different and they can easily avoid competition.

4.5.3 Parasitism

This is an interaction in which one species, parasite benefits and the other, host, is harmed. For the parasite, which is generally much smaller than its host, the host is a source of both food and shelter. The parasite does not kill its host immediately after infecting it, otherwise, the parasite would soon become extinct being unable to reproduce.

Parasitic organisms generally have higher reproductive rates and exhibit a greater host specificity. They are often highly specialized in structure, physiology and life history patterns, all in response to their mode of life and to problems associated with dispersal from one host to another. Some animal groups which include tapeworm and malarial parasite have become adapted to a totally parasitic life. Such specialized species as the human malarial parasite, have very complex life cycles since a vector is also involved along with the host to aid in reproduction and dispersal. Because of host-specificity, many parasites can live in only one or a few related host species, and such intimate host-parasite interaction could be potentially limiting to both populations.

4.5.4 Predation

This is an interaction in which one organism, predator kills another, prey for food. this is a process of paramount importance not only in natural ecosystems but to man also, because he is either directly a predator himself (as when he captures fish from the sea, hunts game animals in a forest), or has to deal with natural predators which are directly harmful to him or kill prey that are beneficial to him.

First let us consider the importance of predation in nature. Following are its important roles:

1) Predation helps to channelise through different trophic levels the energy fixed by photosynthetic plants. But for predation, the 'grass-deer-tiger' food chain would not obviously exist! Remember, the grass 'considers' deer as its predator; in this sense, to a plant the sparrow that eats its seeds is also a predator.

2) Predators can bring down the intensity of interspecific competition in a community by selectively preying on the competitively superior species and keep their densities low. This permits the weaker species to persist in the habitat.

3) Predators also appear to be responsible for maintaining a high species diversity in many biological communities. Experimental removal of all predators from a community has been known to lead to the elimination of some species and a general decline in species diversity.

4) Predators in some cases can regulate the population densities of their prey. Predation is obviously not beneficial to the individual organism that is killed and eaten as food, but to the prey population as a whole, the predator could be very beneficial.

In an ideal situation, the prey and predator populations show what are called 'coupled oscillations' over a period of time.

Let us see how these oscillations come about : in a habitat with plentiful resources, prey numbers start increasing, consequently predators get more food and produce more offspring. With increasing predator population in the habitat, more and more prey are killed bringing their population size down eventually.

Now, because of low prey densities in the habitat, the predators can not obtain enough food and therefore, their numbers start falling. These events lead to oscillation in the densities of both prey and predator. It is important to mention here that the situation could turn out to be entirely different if the predator is not 'prudent' or he is 'too efficient' at killing the prey. Under these conditions, the predator will seek out and kill every prey individual, drive the prey species to extinction, and subsequently will eliminate himself, through starvation!

If a predator is choosy and so specialized that it depends almost exclusively on a particular prey species, then we can expect the evolution of these prey and predator to be linked to each other. In this 'co-evolution', the prey tends to evolve defenses specifically to escape from that predator while the predator tends to evolve adaptations to counter those defenses and become more efficient in capturing that prey.

As we stated earlier, predators could help keep the prey population under check. Although such is not always the case with large-sized prey, for example, moose, wildebeest, etc.. There is strong evidence that populations of many small prey species like insects, zooplankton, etc., in nature are kept under control by their predators. If the natural predators are eliminated, the prey population is released from predation pressure and increase in an exponential fashion. This is the explanation for the sudden and unpredicted increase in the densities of pests when chemical pesticides are sprayed nonselectively by man with the intention of actually killing them!

The chemicals certainly kill a fraction of the pest population in the area, but more importantly, they also kill their natural predators which used to keep their prey numbers under control. With the natural predator check removed, the pest populations grow, nullifying any beneficial effect of pesticide application.

SAQ 7

Match the best suited word from Group A to the explanation given in Group B.

Group A	Group B
i) Mutualism	a) Two different species of Paramecium kept in one medium and one species eliminated.
ii) Competition	b) Coaction which is beneficial to both species living in the same habitat.
iii) Parasitism	c) Decay of dead leaves in the soil by fungus
iv) Decomposer	d) Two individuals living together and one is harmful to the other.

4.6 INTERACTION BETWEEN MAN AND OTHER LIVING COMPONENTS

When human species started evolving about 2 million years ago, man's interaction with nature was more direct and intimate since he was a hunter-gatherer and thus a predater like any other large animal predator. Agricultural and socio-cultural evolution through ages has changed the human species completely—no longer do we need to chase a wild buffalo with bow and arrows or dig out tuberous roots from soil with crude stone tools to satisfy our daily food requirements! Yet, the impact of man on the biosphere had never been so massive and alarming as it is now. True, man does not interact directly with many plants and animals, except the domesticated varieties, but nevertheless he exerts profound influence on the living beings around him. His multifarious activities undertaken for his own benefit invariably alter the environment in ways that harm some species and at times benefit some undesirable species. Deforestation due to growing population pressure leads to habitat alteration—from forests to pastures to crop lands, which causes the decline or total loss of forest-dwelling species. Often the changes in an ecosystem caused by human activity are gradual and not dramatic enough to be recognized readily.

With the advent of Indira Gandhi Canal in northwestern Rajasthan, the land use patterns are already changing. The traditional goat and sheep husbandry is being replaced by husbandry of cows and buffaloes. Similarly, desert biologists are noticing that the truely desert rodent species are being replaced by species belonging to areas with more vegetation. In modern times, destruction and alteration of natural habitats are the greatest causes for the alarming rate of the disappearance of many species. Biologists believe that as a consequence of deforestation in the tropics, thousand (if not lakhs) of insect species are becoming extinct even before they are discovered, named and described.

We mentioned earlier the importance of a predator being 'prudent'. A prudent predator whose survival and growth are dependent on a particular prey species should not overexploit it to extinction but should ensure its continued well being for his own benefit. Is man a prudent predator? The irrecoverable loss of commercial fishery of important fish species in the North Sea and a few other similar examples from elsewhere, cast doubts on a positive answer we might be tempted to give to this question.

The existence in nature of mechanisms by which predators keep prey populations under control should have received due attention when we attempted pest control by chemical means. No doubt, some degree of chemical control of pests and competitors is necessary when the objective is to improve net food production and creation of a disease free environment. But in many instances the chemical control measure backfired because of the evolution of insecticide—resistant strains and due to the elimination of non-target organisms some of which were natural predators of pests. Having realized that it is impossible to win the war against insect pests, the present thinking is not in terms of pest control but pest 'management', an approach in which biological control methods play a vital role. Since many of the pesticides in use are not specific, they harm countless non-target species, seriously affecting the normal functioning of ecosystems. You will learn more about pesticide pollution and its consequences in Block 3.

Lastly, the ecological imbalance caused by human activities is not exclusively through the loss of certain species, but at times through introduction of exotic species into a community of indigenous flora and fauna. Some of these introductions were intentional, others accidental. These exotic species include the controversial Eucalyptus, the ubiquitous water hyacinth and the mosquito fish. Nearly all standing water bodies in India are being covered by the water hyacinth which is now an uncontrollable weed. Another noxious weed spreading alarmingly in dry tracts all over the country is the Congress weed, Parthenium which is believed to have 'sneaked' into our country as seed along with the wheat imported from USA under PL480.

SAQ 8
What are the present ecological consequences of Indira Gandhi Canal in Rajasthan?

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4.7 SUMMARY

In this unit you have learnt the following:

- Practically all the energy comes from the sun for the functioning of an ecosystem. The flow of energy is always unidirectional and is governed by two laws of thermodynamics. First law of thermodynamics states that energy cannot be created or destroyed while the second says in essence, that as the energy is used to do work some energy is wasted as heat at each energy transformation. As a consequence of this all living systems need continuous supply of energy.
- Nutrients essential to organisms are distributed in various chemical forms in air, rock or soil, water and in some cases living things. Over time elements move from one sphere to another in biogeochemical cycles. Key cycles described in the unit are carbon, nitrogen, water and sulphur. Soil microorganisms play a key role in cycling of elements particularly nitrogen and sulphur.
- The patterns of interaction between living things are an important dimension of ecology. Many factors determine the growth of a population. Growth rate can be calculated from birth and death rates as well number of organism immigrating and emigrating to and from an ecosystem.
- Factors affecting growth rate are food supply, availability of habitat, social interaction, climatic changes, disease, predation, etc.
- The maximum number of individuals of a particular species that an ecosystem can support is called its carrying capacity. The size of a stable population fluctuates around or below the carrying capacity.
- A description of everything about a species, and how it relates to other species in the ecosystem, what habitat it prefers, what it eats, how and when it reproduces, defines the niche of that species.

- Interspecific relations are the interactions between individuals of different species. These may be beneficial or harmful. This includes competition, parasitism and predation.
- Human beings have caused several ecological changes because of their continuous interference in the environment for a comfortable living .

4.8 TERMINAL QUESTIONS

1) How is the second law of thermodynamics relevant to energy flow from one tropic level to another?

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2) Which one among the following statements describes the flow of energy in the ecosystem? Tick the correct choice.

   The flow of energy along different trophic levels follows on the average a 10% rule, that is :

   a) 10% energy is left unutilised in successively higher trophic levels. [ ]

   b) 10% energy is left at each trophic level through respiration. [ ]

   c) 10% energy is utilised at each trophic level for growth and development. [ ]

3) a) What does 'biological nitrogen fixation' mean?

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   b) Why don't farmers need to buy carbon at the fertiliser shop? Why do they need to buy nitrogen?

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4) Keeping in mind the definition of niche choose an organism that you are familiar with and describe its niche as completely as you can.

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5) Human beings have expanded the earth's carrying capacity for their species. Comment.

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6) a) List three important consequences of interspecific competition.

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b) How is commensalism different from mutualism?

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4.9 ANSWERS

Self Assessment Questions

1) a) i) food, herbivores
iii) carnivores, herbivores
ii) respiratory, unutilised
iv) energy, trophic.

b) i) matches b); ii) matches c) and iii) matches a)

2) gaseous, atmospheric, producers, decomposers, organic, formation, combustion, carbon, rise, thermocline.

3) a) (ii) b) (iv) c) (i)

4) 75% 0.004%, cold, snow and glaciers.

5) 1) c 2) c

6) c

7) i) matches (b); ii) matches (a); iii) matches (d); iv) matches (c)

8) i) Changes in animal husbandry patterns sheep and goats replaced by cows and buffaloes.
ii) Desert species of rodents gradually replaced by species that are found in areas with comparatively more vegetation.

Terminal Questions

1) According to second law of thermodynamics, entropy increases when energy changes from one form to another. So, energy moving from one trophic level to another is not 100% efficient, only a fraction is retained in organisms for their functioning. The rest is lost as heat or unutilised, energy.

2) c)

3) a) The atmospheric nitrogen which cannot be used directly by many autotrophs is converted to usable nitrites and nitrates by certain species of bacteria and bluegreen algae. This is nitrogen fixation.

b) Because plants can take carbon directly from atmosphere while for nitrogen, plants need special nitrogen fixing bacteria as they are unable to take nitrogen directly from atmosphere.

4) lizard

Habitat niche : wall in the house

Food niche : insects, second level carnivore
competes with spider

Reproductive niche :	hot humid rainy season
Physical and chemical niche :	nocturnal, active during summer season while hibernates during winter
Work :	acts as scavenger

5) Human beings have been able to expand the carrying capacity through technological, social and other cultural changes. They are increasing food production, controlling diseases and using large amounts of energy and matter resources to make normally uninhabitable areas of the earth habitable.

6) a) 1) Extinction of inferior species

2) Increasing specialisation

3) Formation of new species

b) In commensalism only one species benefits from the association and the other is unaffected (+ 0) while in mutualism both species are benefitted (++).