8

ECOLOGICAL PRODUCTION AND ENERGY FLOW IN THE ECOSYSTEM

As described in the 6th chapter the biosphere is the largest ecosystem. There is input of matter and energy in the ecosystem to build biological structure, to reproduce and to maintain necessary internal energy level so that the ecosystems may function properly. There is also export of matter and energy from the ecosystems. When there is balance between the input of matter and energy and output (exit) of matter and energy, the ecosystems tend to be in equilibrium state. All organisms in the biosphere are like machines because they use energy to work and convert one form of energy into another form of energy. The energy pattern and flow are governed by the first and the second laws of thermodynamics.

First Law

The first law of thermodynamics is known as the conservation of energy which states that in any system of constant mass, energy is neither created nor destroyed but it can be transformed from one type to another type (example, electrical energy can be converted into mechanical energy). In terms of ecosystem, energy inflow or energy input into the system will be balanced by energy outflow from the system.

Second Law

The second law of thermodynamics states that when work is done, energy is dissipated and the work is done when one form of energy is transformed into another form.

8.1 SOURCES OF ENERGY

All sources of energy of the biospheric ecosystem are virtually out side the biosphere. The major source of energy is the solar radiation and other minor sources of biospheric energy are cosmic radiation, geothermal energy and energy subsidies released from storage in fossil fuels. The sun is the most important source of energy for the proper functioning of the ecosystem because the solar radiation is converted by green plants into food or chemical energy which is used by plants themselves, animals and man. Solar radiation also helps directly and indirectly in the circulation of matter in the biospheric ecosystem (the process is called as biogeochemical cycles comprised of water or hydrological cycle, chemical elements cycles, sediment cycle etc.)

The flux or inflow of solar energy in the biosphere has been estimated differently by various scientists. Following the estimate of Ian Simmons (1982) the solar energy reaching the top of the earth's atmosphere is 520×10^{22} Joules (which is $^1/_2$ billionth part of total energy radiated from the sun) every year. Out of this total energy (transmitted from the sun in the form of electromagnetic radiation) about 100×10^{22} Joules reach the earth's surface but 40% of the total solar energy entering the earth's atmosphere is reflected back into space by desert, snow and ice and oceans. Thus 60×10^{22} Joules become available to the green plants for photosynthesis. This part of the solar energy is known as **pool for photosynthesis.** This energy is converted by the green plants into food or chemical energy of which a large part is spent by the plants through respiration. Only 170×10^{19} Joules (which is only 0.2% of the total energy entering the earth's atmosphere) are stored in the biomass (the total mass of the living plant tissues). Thus it is obvious that the flora of the biosphere utilize only 0.2% of the total energy present in the light (solar radiation) of the right wavelength (suitable for photosynthesis by green plants). Man utilizes only less than one percent of the total energy stored in the biomass as accumulated organic matter (fig. 8.1).

FLUX OF SOLAR ENERGY TO LIVING PLANTS

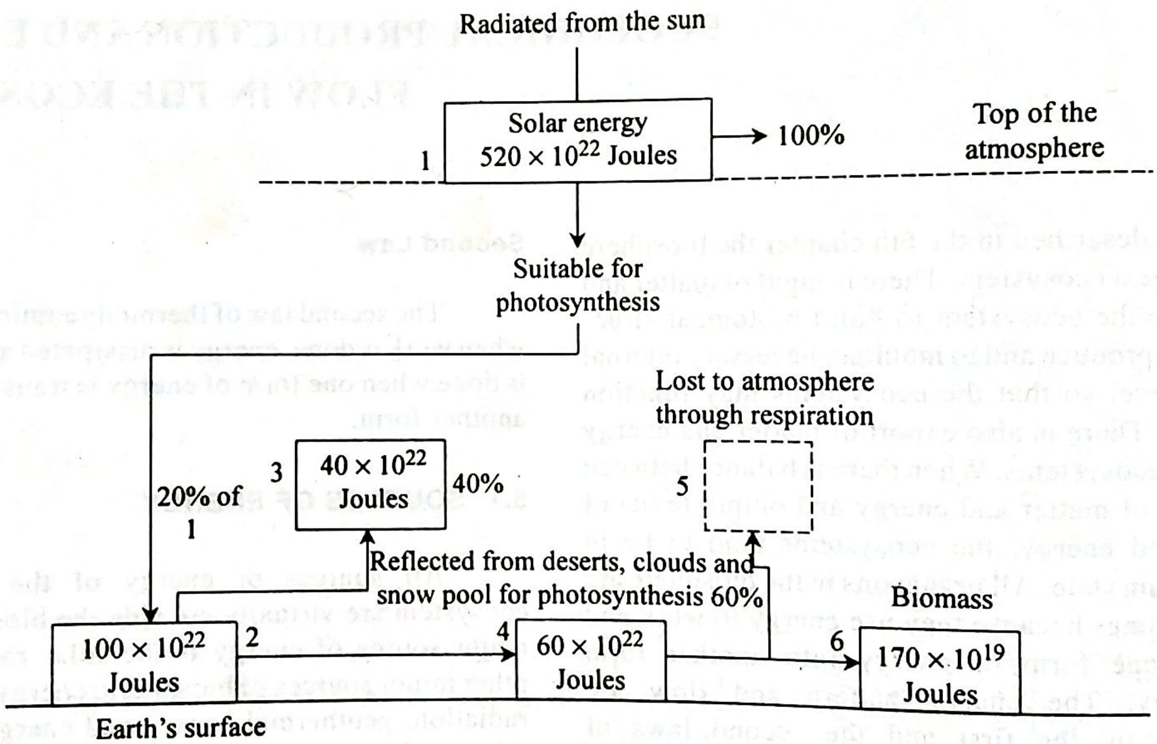

Fig. 8.1 : The flow or flux of solar energy to living plants (Based on Ian Simmons, 1982).

The solar or light energy is transformed into food or chemical energy by the processes of **photosynthesis** by green plants. Some part of this chemical energy is lost to the atmosphere through respiration by the plants and the remaining part is stored in the plants as biomass. The energy is further transferred from one level of organisms to the other level of organisms and it is also used and spent at various levels of organisms. Thus the **flow of energy is unidirectional** and once used and spent is never available for reuse. "Energy is constantly flowing into the biosphere, undergoing various transformations which may involve being stored but ultimately being lost in the form of heat" (P.A. Furley and W.W. Newey, 1983). It is, therefore, necessary to discuss the transformation of solar energy into various forms before describing the mechanism of flow pattern of energy in the biospheric ecosystem.

8.2 ECOLOGICAL PRODUCTION

The solar energy or the sunlight is received and trapped by the green plants in the biosphere. The green plants contain pigment chlorophyll through which they convert solar energy into organic molecules (molecules having carbon). Infact, green plants use light energy to convert carbon dioxide and water into carbohydrates and other biochemical molecules. This process of conversion of light energy into food or chemical energy is called **photosynthesis.** The organisms which produce their own food are called **primary producers.** They are also known as **autotrophs.**

Primary producers fall in two categories e.g. (i) **phototrophs,** and (ii) **chemotrophs.** Phototrophs are those primary producers (green plants) which trap solar energy (light energy) and produce their own food through the process of photosynthesis. The chemotrophic primary producers are primarily chemosynthetic bacteria which produce their food energy through chemical processes wherein simple organic compounds are oxidised to obtain food energy. In other words, chemotrophs use already photosynthesised organic matter which is already present in the biosphere to produce their own food. The primary producers include chlorophyll containing green plants, green purple bacteria, blue green algae and phytoplanktons.

The total accumulated amount of energy stored by the autotrophic primary producers per unit area per unit time is called **ecological productivity.** In fact, the productivity of ecosystem refers to the rate of growth of energy or organic matter per unit time by autotrophic primary producers through the process of photosynthesis with the help of solar energy (light energy). The production of organic matter or energy by autotrophic primary producers is called **primary production** and the green plants involved in the production activity are called **primary producers.**

The productivity of the ecosystem depends on two factors e.g. (1) the availability of the amount of solar radiation to the autotrophic primary producers, and (ii) the efficiency of the plants to convert solar energy (light energy) into chemical energy (food energy) which is used by green plants to build up their tissues. Primary production/productivity is measured in two ways e.g. (i) **gross primary production** (GPP), and (ii) **net primary production** (NPP). Gross primary production is the total amount of energy produced by the autotrophic primary producers at tropic level one. In other words, gross primary production refers to total amount of energy assimilated by autotrophic primary producer green plants. Net primary production (NPP) represents the amount of energy or organic matter fixed or stored at trophic level one. Thus net primary production excludes the amount of energy which is lost through respiration by autotrophic primary producer plants. Net primary production is, thus, gross primary production minus the energy lost through respiration. Net primary production represents the usable amount of energy at trophic level one, which is made available to higher trophic levels. The ecosystem productivity whether, gross or net, is generally measured in gram/m^2/day or year.

Biomass refers to the quantity or weight of living matter per unit area per unit time and is represented in terms of dry weight. Biomass is comprised of plants and animals and therefore it is referred to as **plant biomass** or **animal biomass. Total plant biomass** including both above ground and subsurface plants is called **standing crop.**

It is necessary to draw a distinction between productivity and production. Productivity refers to the rate of increase of biomass whereas production is an amount of biomass of a given unit area at a given time.

Plant and animal biomass may be measured and represented separately. R.H. Whitaker and G.M., Woodwell (1971) have measured the net primary productivity, world net primary production and biomass of plants of major natural ecosystems of the whole earth's surface. Mean net primary productivity for the whole earth is 320 dry grams/

m²/year whereas the mean values for the tropical rainforest, swamps and marshes and estuaries are 2000 dry grams/m^2/year in each case. Very low net primary productivity is of extreme desert, rock and ice (3 dry grams/m^2/year), desert scrub (70 dry gram m^2/year), open ocean (125 dry grams/m^2/year) and Tundra and Alpine ecosystems (140 dry grams/m^2/year). Table 8.1 presents the generalized picture of net primary production and plant biomass of the major natural ecosystems.

Table 8.1 : Net Primary Production and Plant Biomass.

Ecosystems	Mean net primary productivity (dry gram/m^2/year)	World net primary production (10^9dry tons)	Plant biomass (dry kg/m^2) (mean)	World plant biomass (10^9 dry tons)
1. Lake & stream	500	1.0	0.02	0.04
2. Swamp & Marsh	2000	4.0	12.00	24.00
3. Tropical forest	2000	40.0	45.00	900.00
4. Temperate forest	1300	23.4	30.00	540.00
5. Boreal forest	800	9.6	20.00	240.00
6. Woodland & shrub	600	4.2	6.00	42.00
7. Tropical Savanna	700	10.5	4.00	60.00
8. Temperate grassland	500	4.5	1.50	14.00
9. Tundra and Alpine	140	1.1	0.60	5.00
10. Desert scrub	70	1.3	0.70	13.00
11. Extreme desert, rock and ice	03	0.07	0.02	0.50
12. Agricultural land	650	2.10	1.00	14.00
Total land	730	109.00	12.50	1852.00
13. Open ocean	125	41.50	0.003	1.00
14. Continental shelf	350	9.50	0.01	0.30
15. Attached algae and estuaries	2000	4.00	1.00	2.00
Total ocean	155	55.00	0.009	3.30
Total for earth	320	164.00	3.6	1855.00

I.G. Simmons (1974) has estimated the net primary productivity for major world biomass (table 8.2). The mean net productivity of the whole world is 303 gram/m^2/year whereas total net productivity of the whole area of the world is 155.2×10^9 tonnes per year. Mean net primary productivity of the continental and oceanic ecosystems is 699 and 155 gram/m^2/year. It is obvious that mean net primary productivity of the continental ecosystems is about 4 times greater than the oceanic (marine) ecosystems. But the total net productivity of the whole area of the continental ecosystems (102.2 × 10^9 tonnes per year) is only double of the marine (oceanic) ecosystems (55.0 × 10^9 tonnes per year) inspite of the fact that the oceanic ecosytems cover about 71 percent of the total area of the globe.

Table 8.2 : Estimated Net Primary Productivity of Major World Biomass

Vegetation Unit	Mean Productivity (g/m^2/year)	Total of net productivily (10^9 tonnes/year)
1. Forests	1290	64.5
2. Woodlands	600	4.2
3. Tundra	140	1.1
4. Desert scrub	70	1.3
5. Grassland	600	15.0
6. Desert	3	
7. Cultivated land	650	9.1
8. Fresh water	1250	5.0
9. Reefs and estuaries	2000	4.0
10. Continental shelf	350	9.3
11. Open ocean	125	41.5
12. Upwelling zones	500	0.2
Total continental	669	100.2
Total Oceanic	155	55.0
World Total	303	155.2

Source : I.G. Simmons, 1974

Since the primary productivity of a natural ecosystem largely depends on the amount of available solar radiation, there is positive correlation between primary productivity and solar radiation. Since there is marked decrease in solar radiation received at the earth's surface from equator towards the poles, primary productivity also, on an average (besides a few intermediate zones of exeception) decreases markedly towards the poles. This results in spatial variations in primary productivity at global, regional and local sçales. E.P. Odum (1959) has identified three levels of primary productivity of terrestrial ecosystems at world scale (fig. 8.2) as follows :

➤ **the regions of high ecological productivity represented by shallow water areas, moist forests (tropical and temperate), alluvial plains and regions of intensive farming;**

➤ **the regions of low ecological productivity represented by arctic snow covered wastelands, and**

➤ **intermediate ecological productivity e.g. grasslands, shallow lakes and farmlands except intensively cultivated areas.**

Though the productivity of ecosystem largely depends on the availability of required amount of solar radiation (sunlight) and the efficiency of plants to use this energy, there are also other factors which affect and control the ecosystem productivity e.g. **abiotic factors** (temperature, water quantity and depth of water, and above all climate and chemical factors-nutrient supply) and **biological factors** (mode of interactions between various populations such as mutualism, parasitism, predation etc. and internal instinctive control mechanisms within the populations such as social organization, territoriality and social hierarchies). When the aforesaid factors are favourable, there is quite high relative level of productivity. When one or more factors are in short supply or are not favourable to ideal ecosystem productivity ecological productivity becomes low. Such factor, which inhibits ecosystem productivity and therefore ecological production, is called **limitting factor.** For example, water is a limiting factor in the hot desert areas because sufficient vegetation cannot develop due to scarcity of water though sunlight, temperature

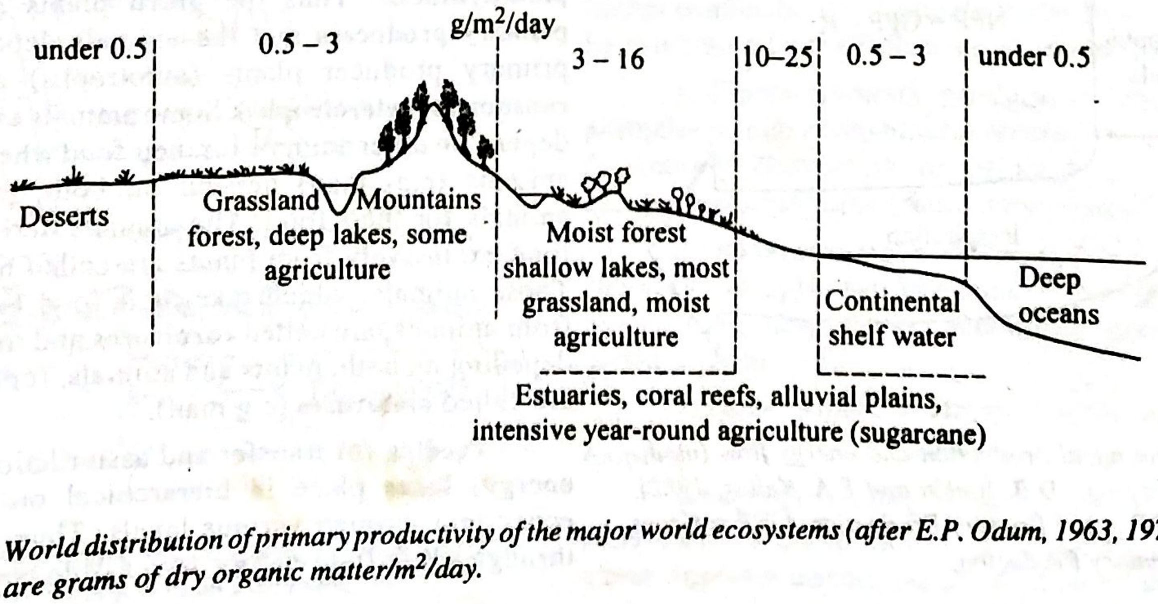

Fig. 8.2 : World distribution of primary productivity of the major world ecosystems (after E.P. Odum, 1963, 1971). The units are grams of dry organic matter/m^2/day.

and nutrients are plentiful. Similarly, sunlight and temperature are limiting factors in polar areas.

It is important to note that there is also variation in the rate and amount of photosynthesis with the season (more photosynthesis and hence more gross primary production during summer season than winter season of a year) and with the age of the plant, animal or microbe. In the initial stages of the development of living organisms **gross primary production** (GPP) and **net primary production** (NPP) both increase but after the attainment of mature stage of biotic community there is increase in GPP but at slow rate, whereas NPP decreases because of increase in respiration due to greater consumption of energy in respiration.

The herbivorous animals depend on autotrophic primary producer plants for their food.

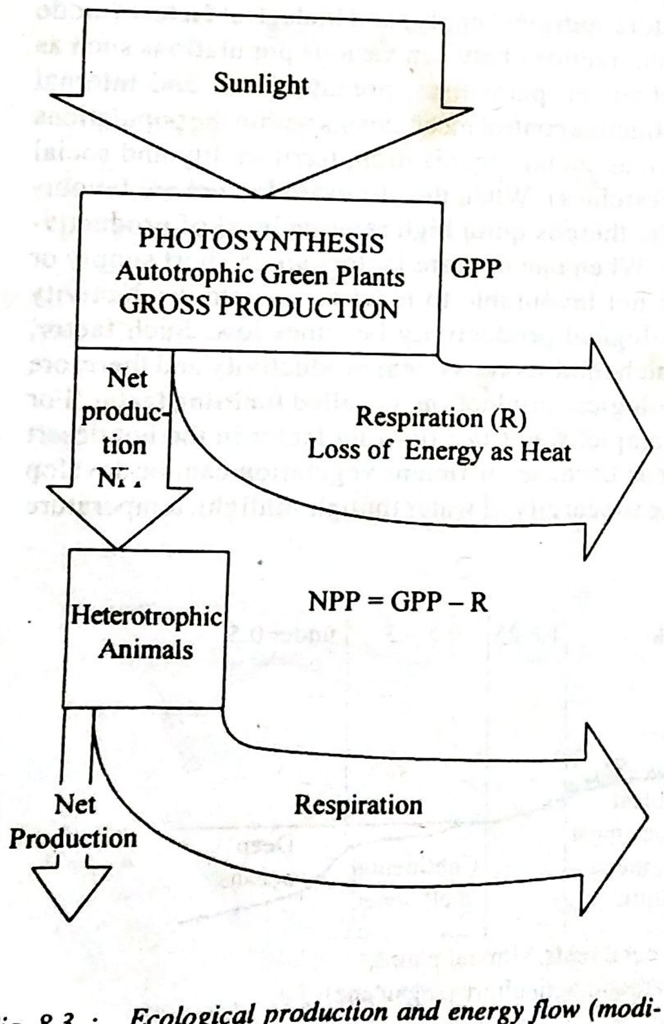

Fig. 8.3 : Ecological production and energy flow (modified from D.B. Botkin and E.A. Kellar, 1982). NPP = Net Primary Production; GPP = Gross Primary Producton.

Thus the herbivores build up their tissues through the food energy derived from autotrophic plants. These herbivorous animals are called **primary consumers.** The total amount of matter or energy assimilated by herbivorous animals is called **secondary production.** The **gross secondary production** (GSP) represents the amount of energy assimilated and accumulated by heterotrophs whereas the **net secondary production** includes the amount of energy or organic matter assimilated and accumulated by heterotrophs minus energy lost through respiration. The **net community production** (NCP) represents net secondary production by all heterotrophs at different trophic levels and unused primary production.

8.3 TROPHIC LEVELS, FOOD CHAINS AND FOOD WEBS

As stated earlier, green plants are very important biotic component of the biospheric ecosystem because these green plants manufacture their own food which becomes source of food energy for all types of organisms in the biosphere. Plants manufacture their food with the help of carbon dioxide, inorganic salt (phosphorous and nitrates), water and sunlight. Carbon dioxide is taken by plants from the atmosphere through their leaves during day time while inorganic salts and water are taken by plants from the soils through their roots by the process of **root osmosis.** The green pigment chlorophyll of plants traps solar radiation or sunlight. Now plants convert water and carbon dioxide into starch and sugar with the help of sunlight. The whole chain of this process is called **photosynthesis.** Thus the green plants are called **primary producers** and the animals depending on primary producer plants (autotrophs) are called **consumers (heterotrophs).** Some animals exclusively depend on other animals for their food whereas some animals (e.g. man) depend on both, plants and animals for their food. The animals deriving their food exclusively from plants are called **herbivores.** Those animals, which take their food exclusively from animals, are called **carnivores** and the animals depeding on both, plants and animals, for their food are called **omnivores** (e.g.man).

Feeding (or transfer and assimilation of food energy) takes place in hierarchical order in the ecosystem through various levels. Thus the levels through which food energy passes from one group of organisms to the other group are called **trophic levels.** The chain of transformation and transfer of food energy in the ecosystem from one group of organisms to the other group through a series of steps or levels (trophic levels) is called **food chain.** In other words, the chain of transfer of food energy from one group of organisms to the other group in the biosphere (ecosystem) is called **food chain** and the point where food energy is transferred from one group of organisms to the other group is called **trophic level.** The concept of trophic level is based on the classic work of R.L. Lindman (1942) who pointed out "that living organisms can be grouped into a series of more or less discrete trophic levels with each level depending on preceding one for its energy (food) supply". On an average four trophic levels of a food chain are identified.

(1) **Trophic level 1 :** The base of the food chain is formed by autotrophic primary producer organisms which include green plants. This base of the food chain is called trophic level 1 where green plants produce their food through the process of photosynthesis with the help of sunlight, water, carbon dioxide and inorganic salts and they consume the produced energy to build their tissues and bodies. The trophic level 1 is also the source of food for all other organisms of the food chain. All the green plants are the members of trophic level 1.

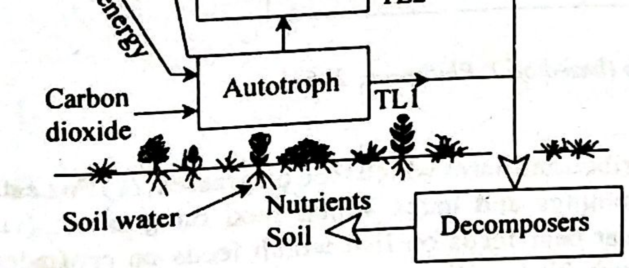

Fig. 8.4 : Functional relationships between different trophic levels in an ecosystem.

(2) **Trophic level 2 :** The organisms, who do not produce their food themselves but depend on primary producers (of trophic level 1) for their food, are included in trophic level 2. These organisms are animals and are called **primary consumers.** They are basically grazers like sheep, cows, rabbits, goats, deers etc. These animals are also called **herbivores.** The trophic level where food energy is transferred from primary producers to primary consumers is called trophic level 2 (fig. 8.4 and 8.5).

(3) **Trophic level 3 :** The animals, who depend on animals mainly herbivorous animals for their food, are included in this trophic level. These animals are called **carnivores** and **secondary consumers** because they depend on the primary consumer animals of herbivorous group of trophic level 2. Carnivores include (I) land animals-lions, hawks, beers, leopard, eagles etc,; (II) animals living in the soils-bacteria which decompose dead herbivorous animals; (III) aquatic animals-herring. The trophic level where energy is transferred from primary consumers to secondary consumers is called tropic level 3 (figs. 8.4 and 8.5).

(4) **Trophic level 4 :** Those animals are included in this trophic level which take their food either directly or indirectly from all the three lower trophic levels. Man is the most important member of this trophic level because he derives food and fuel from the green plants, commodities from second and third trophic levels. Such animals (as man) are called **omnivores.** Decomposers also derive their energy from all the trophic levels (fig. 8.4).

A **food chain** is in fact the sequence of energy transfer from the lower trophic levels to the upper or higher trophic levels. A simple linear food chain may be illustrated by the following example (fig. 8.5).

1. Plants (primary producers)→herbivorous animals (primary consumers)→carnivorous animals (secondary consumers or primary carnivores)→ carnivores/omnivores (secondary carnivores).

2. Grass (primary producer) is eaten by→sheep (herebivores, primary consumer)→sheep is eaten by→wolves (carnivores, secondary consumer or primary carnivore).

3. **Grass→insects→frogs→snake→hawk→ leopard.**

When the feeding relationships in a natural ecosystem become more complicated, the food chain does not remain simple and linear rather it is

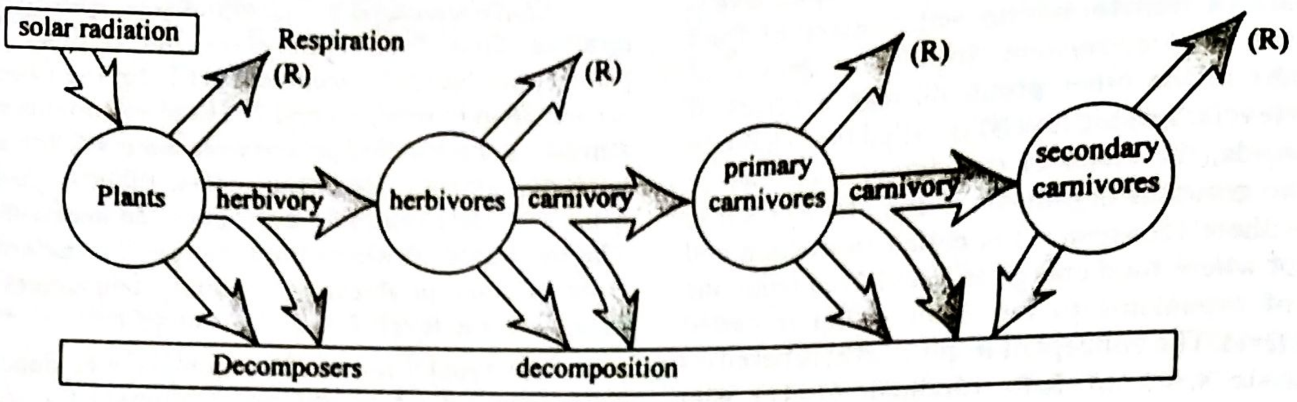

Fig 8.5 : A simple linear food chain and energy flow.

also complicated by several inter-connected overlapping food chains. This happens when greater number of species feed on many kinds of prey. Such complicated food chain is called **food web.** For example, there are various pathways of transfer of energy between diatoms (primary producer in marine ecosystem) and adult herring (fig. 8.6) e.g. (i) herring feeds on arrow worms which feed on barracle larva which feeds on diatoms; (ii) herring feeds on sea butterfly which feeds on pseudo calanus, acortia, temora, calanus, all of which feed on diatoms, and so on.

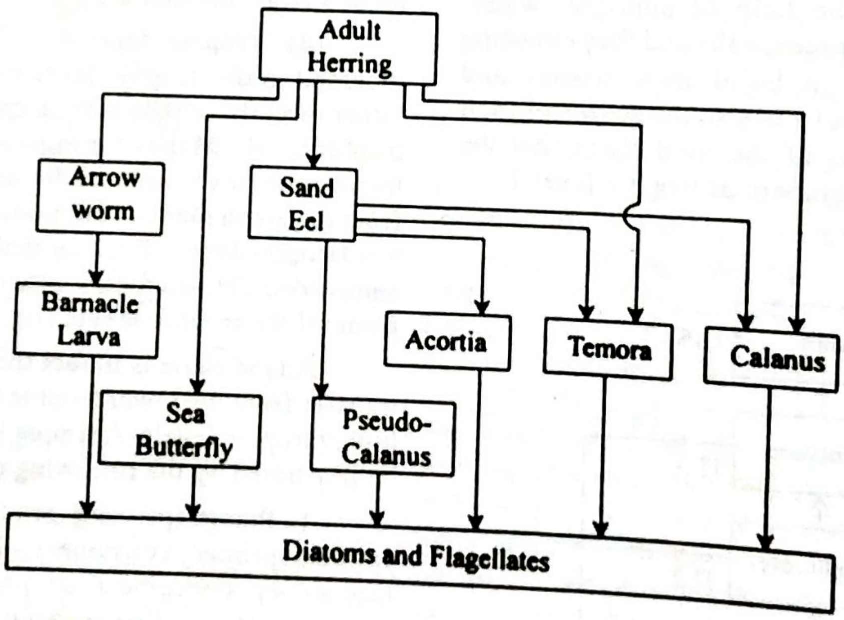

Fig.8.6 : Illustration of a marine food web (based on J. Phillipson, 1966).

Figure 8.7 illustrates another example of complicated food web in a polar (arctic) ecosystem where there are several inter-connected food chains. e.g. (i) Man eats caribou which feeds on grasses; (ii) Man feeds on whales which eat crustacea which feed on diatoms; (iii) Man eats walrus which eats crustacea which feed on diatoms; (iv) Wolf eats caribou and hares which feed on grasses; (v) Fox eats lemmings and hares which feed on grasses; (vi) Polar bear feeds on fish which feeds on crustacea which feed on diatoms and so on.

The nature of food chains and food webs depends on the richness or poorness of biodiversity of a natural ecosystem. The richer the biodiversity, the longer and more complicated the food chains and food webs. The ecosystem stability also depends on biodiversity and food chains and food webs. As the biodiversity increases, the food chains and food webs become longer and more complicated, so the ecosystem becomes more stable. A simpler food chain represents unstable ecosystem and poor biodiversity.

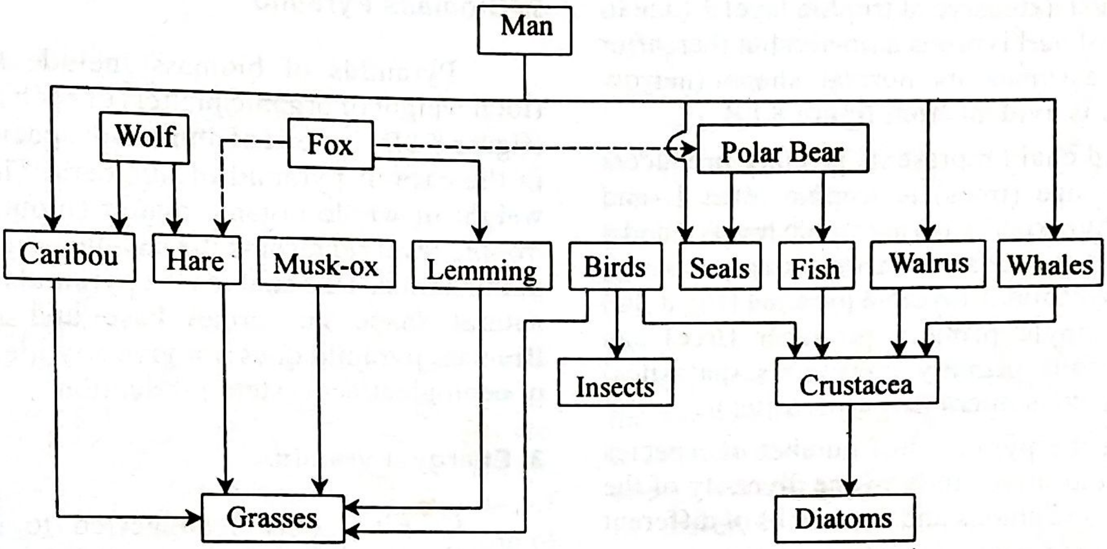

Fig. 8.7 : Illustration of a complicated polar (arctic) foodweb (based on J. Phillipson, 1966).

8.4 ECOLOGICAL PYRAMIDS

If we look into the nature and pathways of transfer of energy through different trophic stages (levels) and total biomass at each trophic level we find certain common characteristics e.g. (i) The number of species tends to decline successively from the base of the trophic level (trophic level 1) to the top of the trophic level. (ii) The total biomass tends to decrease progressively from the base of the trophic level through successive higher trophic levels to the top. (iii) The energy availability at each successive higher trophic level decreases. Thus, it is obvious that the number of species, the total biomass and energy availability decrease with successive higher trophic levels in the food chain in such a way that the shape becomes like a pyramid. This is called **ecological pyramid.** There are three types of ecological pyramids e.g. (i) the pyramids of numbers, (ii) biomass pyramid, and (iii) energy pyramid.

1. Number Pyramids

Number pyramids include only the number of species and not their sizes (whether the organisms have larger bodies or smaller ones). C. Elton (1927) has pointed out that "the animals at the base of a food chain are relatively abundant, whilst those at the end are relatively few in number, and there is a progressive decrease in between the two extremes". Thus, the pyramid of number means progressive decrease in the number of species with successive higher trophic levels. On an average the primary producers or the autotrophic green plants are small in size but very large in number at the base of the pyramid (representing trophic level 1) because these have to provide food to the animals of trophic level 2 which are smaller in number (than the plants at trophic level 1) but larger in size. Similarly, the number of animals at trophic level 3 is smaller than the number of animals at trophic level 2 but the size of animals becomes larger at trophic level 3 than at trophic level 2 and so on. For example, if a cow (primary consumer at trophic level 2) feeds on grass (primary producer at trophic level 1), there must be numerous blades of grass to feed and support one cow (figure 8.8A).

In the forest ecosystem the situation is reversed because the primary producers (trees) are very large in size at the base of trophic level (trophic level 1). In such cases a single large tree is capable of supporting a large number of primary consumer animals (herbivores) at trophic level 2, with the result the pyramid of number becomes tapering at the base of trophic levels (due to small number of plants) and most extensive at trophic level 2 (due to large number of herbivorous animals) but thereafter the pyramid assumes its normal shape (narrow upward). This is evident from figure 8.8B.

If a food chain represents primary producers of very large size (trees) at trophic level 1, and parasites and hyperparasites at trophic levels 2 and 3 as primary and secondary consumers respectively, the resultant pyramid is **inverted pyramid** (fig. 8.8C) because one single primary producer (tree) can support numerous primary consumers (parasites) and secondary consumers (hyperparasites).

Though the pyramids of number of species help in the comprative study of the diversity of the structure and food chains and food webs of different ecosystems (e.g. forest ecosystem, marine ecosystem, river ecosystem, lake ecosystem etc.) but these do not give any idea about the total biomass (total weight of living organisms) because pyramids of number consider only the number of organisms and not the size of the organisms.

2. Biomass Pyramid

Pyramids of biomass include the biomass (total weight of organic matter) of each trophic level (figure 8.8D) instead of number of species as is done in the case of pyramid of numbers. Thus the total weight of whole organic matter (biomass) at each trophic level represents the **standing crop** at a single point in time. This enables the pyramid to assume its natural shape i.e. broad base and thin appex. Biomass pyramid does not give any idea of the rate of ecological/ecosystem production.

3. Energy Pyramids

C. Elton (1927) suggested to construct a pyramid of energy to have an idea of ecological

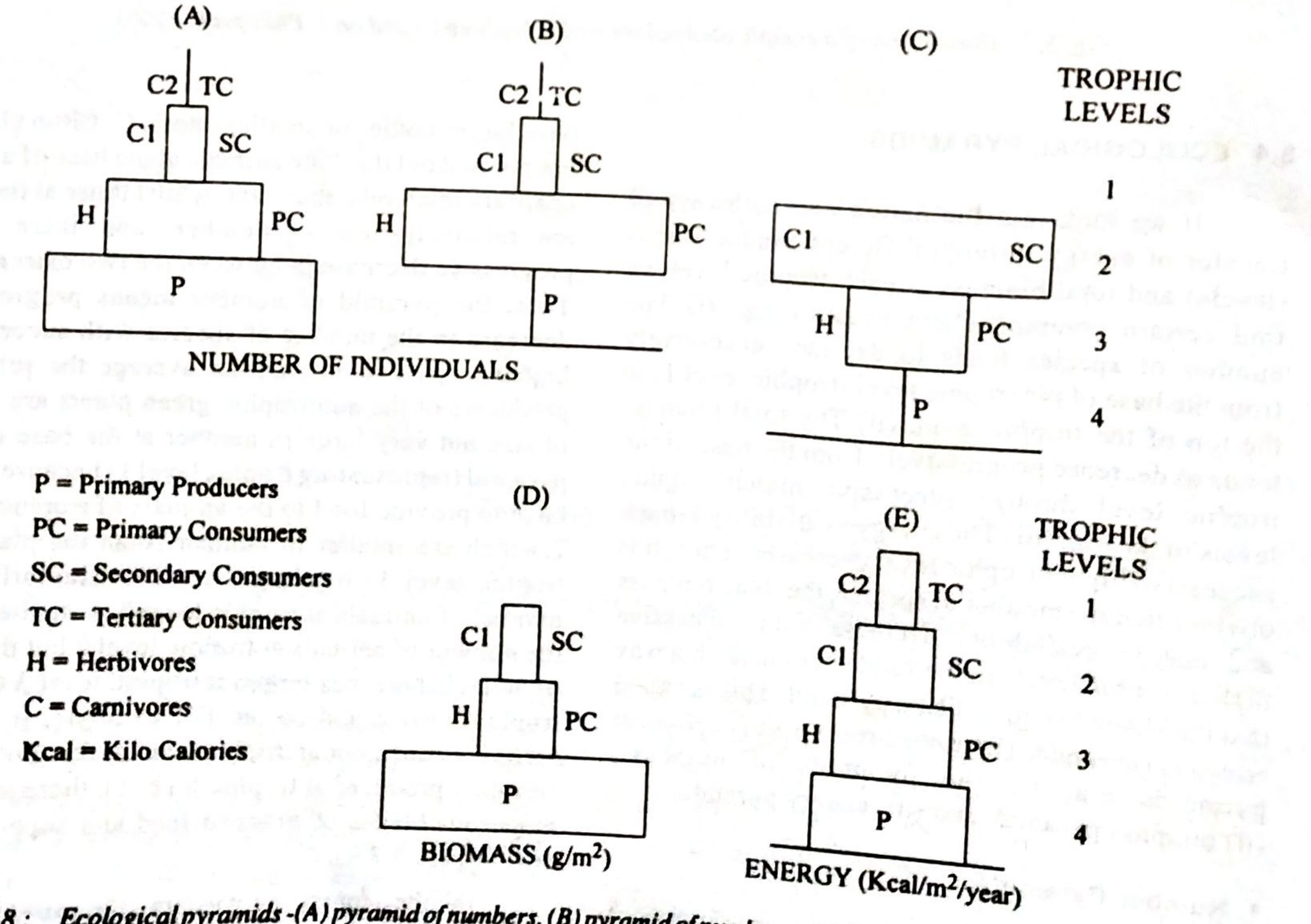

Fig. 8.8 : Ecological pyramids -(A) pyramid of numbers, (B) pyramid of numbers with large tree at the ground, (C) inverted pyramid, (D) biomass pyramid and (E) energy pyramid.

productivity. The energy pyramid is constructed, thus, on the basis of total amount of energy used at each trophic level per unit area per unit time. The total amount of energy used is generally expressed in kilocalories (Kcal) per square metre per day or per year (Kcal/m^2/year). Energy pyramids help in the comparative study of the productivities of different ecosystems (fig. 8.8 E).

8.5 ENERGY FLOW

Solar radiation is the basic input of energy which enters the ecosystem. This solar energy passes through the hierarchy of trophic levels in a food chain and food web and ultimately becomes output from the ecosystem as energy is lost through respiration from each trophic level. **Biosynthesis** is the process of the formation of organic tissue which represents the transformation of solar or light energy into chemical or food energy. **Biodergradation** is the process of breakdown and decomposition of organic matter and thus this process refers to the release of nutrients and food (chemical) energy in the form of heat. The energy flow (transfer of organic molecules) in the ecosystem is unidirectional and is non-cyclic (is not available again for reuse).

The radiant solar energy or light (of the sun) energy is trapped by green plants (primary producers or autotrophs) and is used to prepare food (chemical organic matter) through the process of photosynthesis. Thus autotrophic (or phototrophic) green plants transform a part of solar energy into food or chemical energy which is used by the green plants (primary producers at trophic level 1) to develop their tissues and thus it is stored in the primary producers or autotrophs at the bottom of trophic levels (i.e. trophic level 1).

The chemical energy stored at trophic level 1 becomes the source of energy either directly or indirectly to all of the animals at different trophic levels in a food chain in a natural ecosystem. Some portion of energy is lost through respiration from trophic level 1 and some portion of chemical energy is transferred to plant-eating animals (herbivores) at trophic level 2. Some portion of plants falls down without being consumed by herbivores of trophic level 2 on the ground surface and is ultimately consumed by detrivores or decomposers and thus some energy is also transferred from trophic level 1 to the decomposers living in the soils. It may be pointed out that the transfer of energy from trophic level 1 (green plants, primary producers or autotrophs) is performed through the intake of organic tissues (which contain potential chemical energy) of green plants by the herbivorous animals (when a cow grazes grasses, chemical energy stored in grasses is transferred to the cow).

Thus the chemical energy consumed by herbivorous animals (derived from trophic level 1 through food intake) helps in the building of their own tissues at trophic level 2 a. d thus the energy is stored in them. This stored energy in the bodies of herbivores now becomes the source of energy for carnivorous animals (secondary consumers) at trophic levle 3. A substantial portion of chemical energy is lost through respiration from herbivores at trophic level 2 because the animals have to consume energy for their movement for getting food from green plants. In other words, energy is required for the work to be done and when work is done energy is dissipated and the work is done when one form of energy is transformed into another form (second law of thermodynamics). Some portion of potential chemical energy is transferred to carnivorous animals at trophic level 3 through intake of food from herbivores. Some portion of energy is released by herbivores as wastes (e.g. dung, urine etc.) which are decomposed by detrivores or decomposers. Still some portions of herbivores, when dead, are broken down and decomposed by decomposers (fig. 8.9).

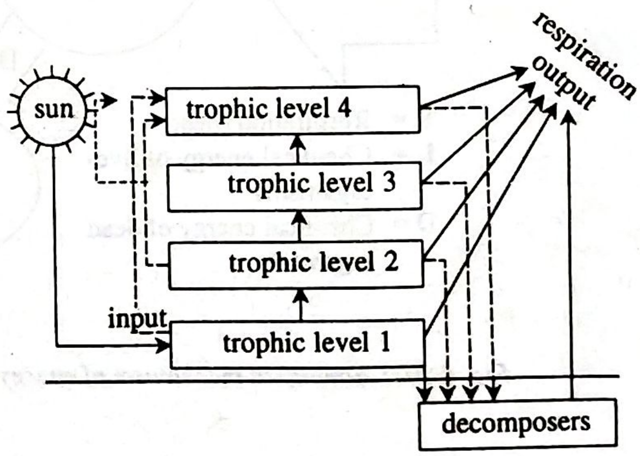

Fig. 8.9 ***Generalized pattern of energy flow in an ecosystem. Solid liines indicate major pathways and dashed lines indicate minor pathways of energy flow.***

A substantial portion of potential chemical energy stored in the bodies of carnivores is lost through respiration from trophic level 3 because the carnivorous animals have to run for greater distances to catch their preys. A portion of chemical energy is transferred to trophic level 4 or tophic level represented by ominivores (those animals which eat both plants and animals, man is the most important example of omnivores). The animals at trophic level 4, mainly man, also take energy from trophic levels 1 and 2 (fig. 8.9). Again some portion of energy is released through respiration from trophic level 4 by omnivores. The omnivores, after their death, are decomposed by the decomposers.

Thus it is obvious from the above discussion and figs, 8.9 and 8.10 that there are three-way pathways of flow of energy in the natural ecosystem as follows :

(i) transfer of chemical energy from each trophic level to the next higher trophic level (i.e. from trophic level 1 to 2, from 2 to 3 and from 3 to 4) and direct transfer of chemical energy from trophic levels 1 and 2 to trophic level 4 (top trophic level);

(ii) transfer of chemical energy from dead organisms of each trophic level to decomposers, and

(iii) loss of energy in the form of heat through respiration from each trophic level and from decomposers (fig. 8.10). The whole amount of heat energy released from different organisms through respiration is lost to the atmosphere and thus is not again available to the organisms for reuse. It is thus evident that the energy flow in the ecosystem is unidirectional and non-cyclic.

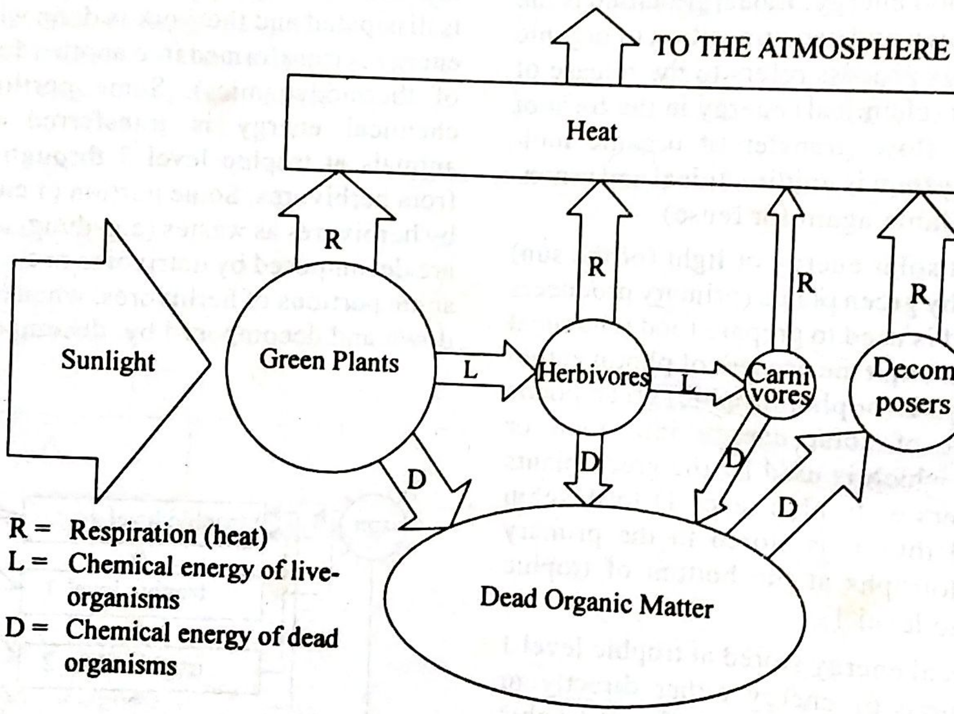

Fig. 8.10 : Simplified mechanism of energy flow in the ecosystem (based on H.J.M. Bowen, 1966).

The first law of thermodynamics, "that in any system of constant mass, energy is neither created nor destroyed but it can be transformed from one type to another type, the energy inflow or input in a system is balanced by energy outflow or output", holds good in the mechanism of energy flow in the ecosystem as elaborated above. Light energy (solar radiation) is transformed into chemical energy (food energy) by autotrophic green plants through the process of photosynthesis. The chemical energy is released as heat energy through respiration by the organisms at different trophic levels. R.L. Lindeman

(1942) has formulated the following five principles regarding the relationships betwen different trophic levels and energyflow in a natural ecosystem.

Principle I : As the distance between the organisms of a given trophic level and the initial source of energy (trophic level 1) increases, the probability of the organisms to depend exclusively on the preceding trophic level for energy decreases. In other words, the organisms at trophic levels 3 and 4 do not depend for their energy only on trophic levels 2 and 3 respectively rather they receive energy from more than one source (trophic level) which means that organisms at trophic level 3 and beyond tend to be 'generalists' rather than 'specialists' in terms of their feeding habit.

Principle II : The relative loss of energy due to respiration is progressively greater from higher trophic levels because the species at higher trophic levels being relatively larger in size have to move and work more for getting food and therefore more energy is lost due to respiration.

Principle III : Species at progressively higher trophic levels appear to be progressively more efficient in using their available food supply, because increased activity by predators increases their chances of encountering suitable prey species, and in general predators are less specific than their prey in food preferences'.

Principle IV : 'Higher trophic levels tend to be less discrete than the lower ones' because the organisms at progressively higher trophic levels receive energy from more than one source (trophic level) and are 'generalists' in their feeding habit and they are more efficient in using their available food supply.

Principle V : 'Food chains tend to be reasonably short. Four vertical links is a common maximum' because loss of energy is progressively higher for higher trophic levels and species at higher levels tend to be less discrete.