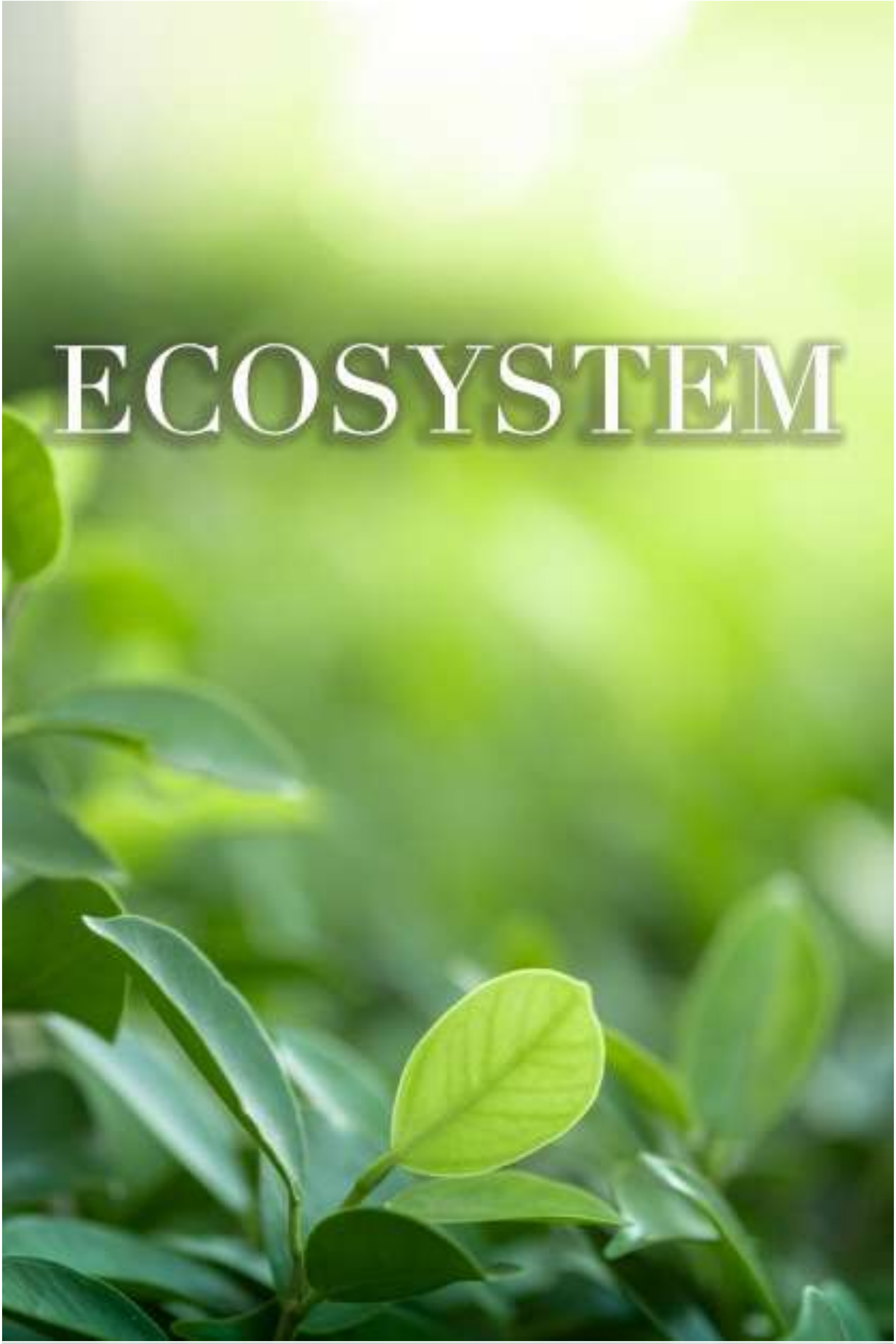
ECOSYSTEM

# ZOOLOGY (HONS.)

**SEMESTER 5**

**CORE COURSE 11: Ecology**

**ZOOA-CC5-11-TH**

**UNIT-4**

# ENERGY FLOW IN ECOSYSTEM

## INTRODUCTION

Energy can be defined as the capacity to do work. All biological activities need consumption of energy which ultimately derives from the sun. The solar energy is converted into chemical energy by the process of photosynthesis which is stored in plant tissues and then transformed into mechanical and heat energy during metabolic activities. In the biological world, the energy flows from the sun to plants and then to all heterotrophic organisms, such as microorganisms, animals and human.

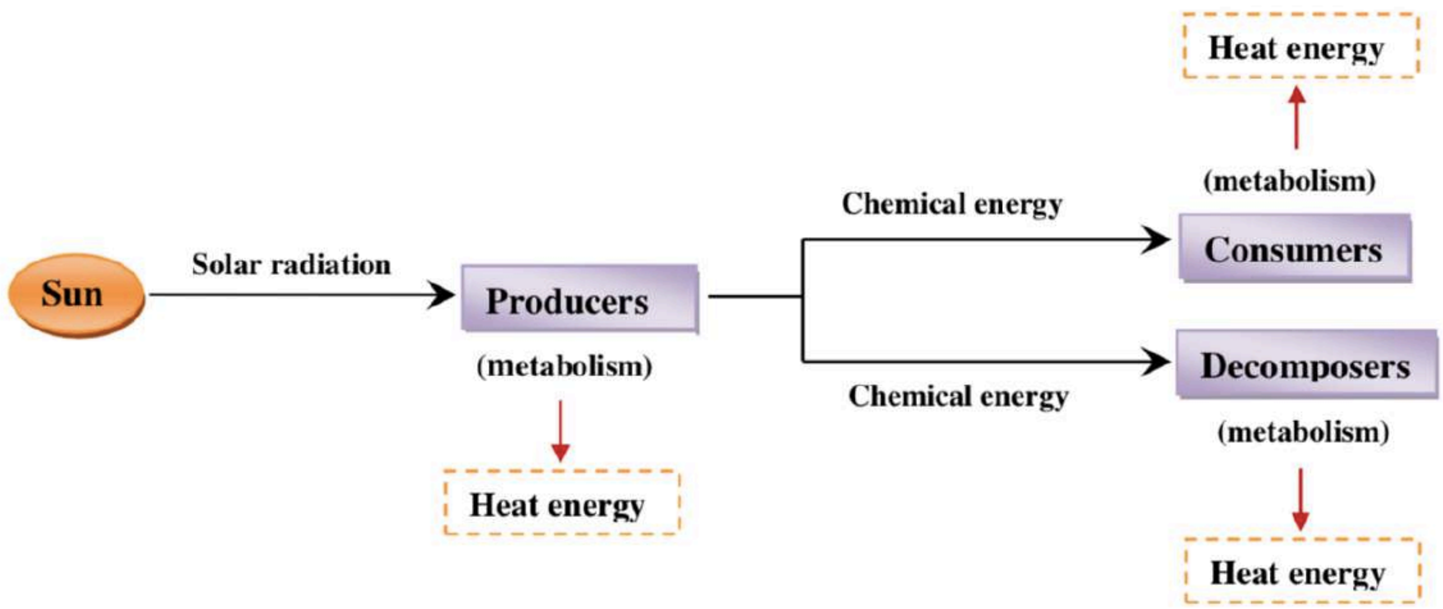


**Figure.1: Energy flow from sun to plant and then to all heterotrophic organisms.**

Mechanical energy is present in two forms, kinetic energy and potential energy. Kinetic energy can be defined as the energy possess by the body by virtue of its motion. It is measured by the amount of work done in bringing the body at rest. The potential energy is the stored energy which becomes useful after conversion into the kinetic energy. All organisms require a source of potential energy, which is found in the chemical energy of food. The oxidation of food releases energy which is used to do work. Thus, chemical energy is converted into mechanical energy. Food is the means to transfer of both matter and energy in the living world.

The unit of measurement of energy is Joule. All forms of energy can be completely converted into heat energy. Heat is measured in calories. One calorie is equal to the heat energy required to raise the temperature of 1 gram of water from 14.5°C to 15.5°C, and one calorie is equal to 4.2 joules.

## ECOLOGICAL ENERGETICS

Ecological energetics consists of energy transformation which occurs within the ecosystems. Ecological energetic consists of:

i) The amount of energy reaching to an ecosystem per unit of area/per unit of time.

ii) The quantity of energy trapped by green plants which they converted into chemical energy (photosynthesis).

iii) The quantity and energy flow from producers to organisms of different trophic levels (consumers) over a period of time in given area.

The energy used by all green plants derived from solar radiations. Only a small fraction of

energy reaches to earth's surface (1 to 5%) is used by green plants for photosynthesis and rest is absorbed as heat by ground vegetation or water. In fact, only about 0.02% of the sunlight reaching the atmosphere is used in the process of photosynthesis.

## THERMODYNAMICS PRINCIPAL

Energy transformation in ecosystems can also be explained in relation to the laws of thermodynamics, which are usefully applied to closed systems.

**I$^{st}$ Law of thermodynamics (law of conservation of energy)**

It state that in a closed system, energy can neither be created nor destroyed but can only be transferred from one form into another. When fuel is burnt to drive a car, the potential energy in chemical bond of fuel is converted into mechanical energy to drive the car. The key point is, the total amount of energy consumed and compare with the total amount of energy produced would always be equal. Such type of energy conservation is also found in biological system. In ecological systems solar energy is converted into chemical energy stored in food materials which is ultimately converted into mechanical and heat energy. Thus, in ecological systems, the energy is neither created nor destroyed but is converted from one form into another. Thus, when wood is burned the potential energy present in the molecules of wood equals the kinetic energy released, and heat is evolved to the surroundings. This is an exothermic reaction. In an endothermic reaction, energy from the surrounding may be paid into a reaction. For example, in photosynthesis, the molecules of the products store more energy than the reactants. The extra energy is acquired from the sunlight, but even then there is no gain or loss in total energy.

**II$^{nd}$ Law of thermodynamics**

The second law of thermodynamics states that processes involving energy transformation will not occur spontaneously unless there is degradation of energy from a non-random to a random form. In other words, the disorder (entropy) in the universe is constantly increasing and that during energy conservation, an energy transformation will spontaneously occur unless there is degradation of energy from a concentrated form into a dispersed form. For example, in man-made machines (closed systems), heat is the simplest and most recognizable medium of energy transfer. The outcome of this law is very significant in biological system. But in biological systems, energy transfer is not a useful medium, as the living systems are fundamentally isothermal and there is no significant variation in temperature between different cells in the organism or between various cells in a tissue of the organism. At each level of conservation, some of the energy is lost as heat. Therefore, the more conservation taking place between the capture of light energy by plants and the trophic level being considered, the less the energy is available to that level. The efficiency of the transfer of energy along food chain from one trophic level to another is generally less than 10 percent as the 90 percent of energy is lost as heat.

The study of energy flow is important in determining limits to food supply and the production of all biological resources. The capture of light energy and its conversion into stored chemical energy by autotrophic organisms provide ecosystems with their primary energy source. The total amount of energy converted into organic matter is the gross primary production varies between different systems. The energy stored in the food material is made available through cell respiration. Chemical energy is released by burning the organic compound with oxygen using enzyme mediated reactions within cells. It produces carbon dioxide and water as waste products. Energy flow is the movement of energy through a system from an external source through a series of organisms and back to the environment. At each trophic level within the system, only the small fraction of the available energy is used for the production of new tissue. Most is used for respiration and body maintenance.

## LINDEMAN'S TROPHIC-DYNAMIC CONCEPT

According to Lindeman (1942), the amount of energy at trophic level is determined by the net primary production (NPP) and the efficiency at which food energy is converted into biomass. The plants use 15 to 70 percent of assimilated energy for the maintenance which is not available to the consumers. The herbivores and carnivores are comparatively more active as compare to plants which uses more assimilated energy for the maintenance. So, the productivity at each trophic level lies between 5 to 20 percent that of the level below it. The percentage of energy which is transferred from one trophic level to the next trophic level is called as ecological efficiency.

In general, secondary producers utilize 55% to 75% of assimilated energy in maintenance. Temperature and moisture are two components of the habitat and the type of species determine the maintenance cost. The dry and hot regions require higher maintenance cost, irrespective of the species. For example, the average maintenance cost of few Indian earthworm species was 6.48, 9.96 and 20.54 kJ/g dry tissue/ month in the winter, rainy and summer seasons respectively in tropical pastures. The maintenance cost varies seasonally and higher was found in summer which was three times more as compare to winter.

## ASSIMILATION ENERGY AND RESPIRATION ENERGY

When the organism eats the food, the digestion and absorption of the food is referred to as assimilated energy, which is used for maintenance, building the tissues or it is removed or excreted in unusable metabolic byproducts. The energy which is lost in the form of heat during metabolic needs is called as respiration energy. A smaller fraction of assimilated energy is excreted in the form of organic or nitrogen containing wastes (ammonia, urea or uric acid) produced when the diet is rich in nitrogen. Assimilated energy of the organism is used for the synthesis of new biomass (production) through growth and reproduction, which may be then consumed by herbivores, carnivores and detritivores. However, organisms are not able to digest and assimilated all food materials like hair, feathers, exoskeleton of insects and cellulose and lignin of plants. These materials are egested by defecation or by regurgitation of pellets of undigested food. Some of these wastes remain relatively unaltered during their passage through an organism, but all these materials are mechanically broken down into fragments by chewing and contractions of the stomach and intestines, which makes them more readily usable by detritus feeders.

## MODELS OF ENERGY FLOW IN ECOSYSTEM

**Single Channel Energy Flow Model**

The principle of food chain and the working of the two laws of thermodynamics can be clarified by means of Single channel energy flow model. All biological activities need energy which they derived from the sun. The energy obtained from the sun is transformed into chemical energy by the process of photosynthesis. This energy is stored in plant tissue and transformed into heat energy during metabolic activities. The solar energy captured by autotrophs never revert back to sun, however, it passes to herbivores and that which passes to herbivores does not go back to autotrophs but passes to consumers. Thus, in biological system, the energy flows from the sun to plants and then to all heterotrophic organisms. The flow of energy is unidirectional and non-cyclic. Due to unidirectional flow of energy, the entire system would collapse if primary source of energy were cut off. At each tropic level there is progressive decrease in energy as heat in the metabolic reactions and also some of the energy is utilized at each tropic level.

This one way flow of energy is governed by laws of thermodynamics which states:

- (a) Energy can neither be created nor be destroyed but may be transformed from one form to another.

- (b) During energy transfer there is degradation of energy from a concentrated form (mechanical, chemical etc.) to dispersed form (heat).

- (c) Energy transformation is never 100% efficient, it is always accompanied by some loss of energy in the form of heat.

Therefore, all biological systems including ecosystems must required energy on a continuous Basis. The energy flow diagram (figure 2)) depicting three trophic levels (box 1, 2 and 3) in a linear food chain. Here the boxes represent the trophic level (producers, herbivores and carnivores) and the pipe depicts the energy flow in and out of each trophic level. There is loss of energy (represented as pipes) at every successive trophic level, there is also a corresponding decline in biomass (represented as box). However, it does not specify any correlation between the biomass and energy. The connection between biomass and energy content may vary according to different conditions. For example, one gram of algae may be equivalent to several grams of forest leaves, due to the fact that the production rate of algae is higher than the forest leaves. The higher biomass of the organism does not necessary indicate the higher productivity. Energy flow in the system balance the energy out flows as required by the First law of thermodynamics and each energy transfer is accompanied by loss of energy in the form of unavailable heat energy (respiration) as stated by second law of thermodynamics.

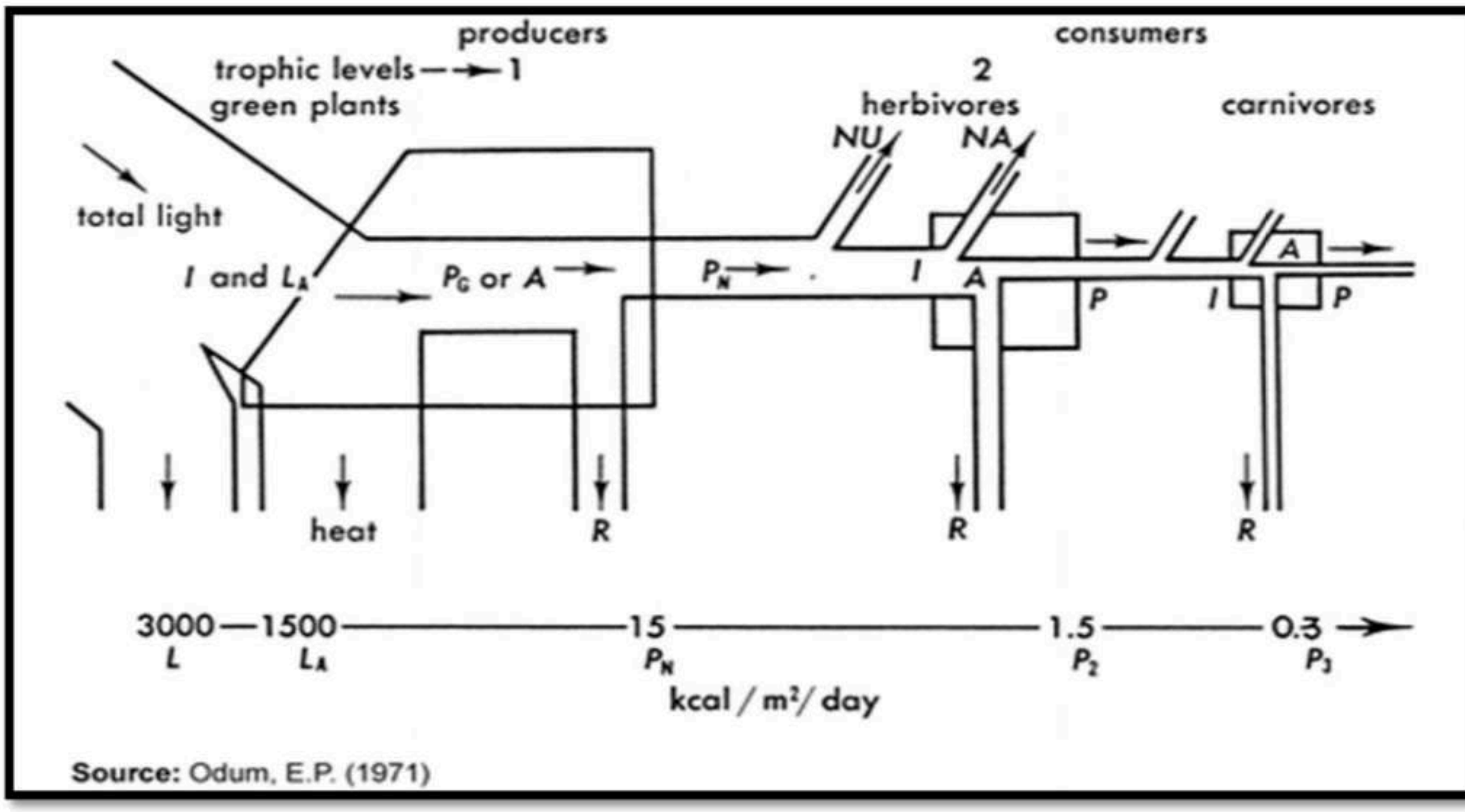


**Figure 2. Linear energy flow model in an Ecosystem. (I-Total energy input, A- total assimilation, LA- Light absorbrd by plants, PG- Gross primary Productivity, PN- Net primary productivity, P-Secondary productivity, NU- Energy not used, NA- Energy not assimilated by consumer, R- respiration).**

The energy flow is significantly reduced at each successive trophic level. Thus, at each transfer of energy from one trophic level to another trophic level, major part of energy is lost in the form of heat or any other form. There is successive reduction in the energy flow whether we consider it in term of total flow (I+A) or secondary productivity and respiration component. Total of 3000 KCal of light falling upon green plants. 50% is absorbed (1500KCal), 1% is converted at first trophic level (15 KCal) Secondary productivity tend to about 10% at successive consumer level although efficiency may be up to 20% at the carnivores level.

**Y-shaped or double channel energy flow model**

Y- shaped model shows a common boundary, light and heat flow as well as import, export and storage of organic matter. Decomposers are placed in separate box to partially separate the grazing and detritus food chains. In terms of energy levels decomposers are in fact a mixed group. Micro consumers (bacteria & fungi) and the macro consumers (animals) differ greatly in size- metabolism relations in two models.

In Y-shaped energy flow, grazing and detritus food chain are sharply separated. It is more practical than simple linear chain energy model as:

- It confirms the basic stratified structure of ecosystem
- It separates the grazing food chain from detritus food chain (Direct consumption of living plants and utilization of dead organic matter respectively) in both time and space.
- Macroconsumer (animals) and microconsumers (bacteria & fungi) differ greatly in size-metabolism relations.

In Y-Shaped model (figure 3)) one arm represents the grazing food chain and the other arm represents detritus food chain. The two arms differ fundamentally in such a way that they can influence primary producers. For Example, in marine bay, the energy flow through grazing food chain is larger than the energy flow via detritus food chain. Whereas reverse is true for forest food chain where 90% or more of net primary production is normally utilized in detritus food chain. Thus, in marine ecosystem the grazing food chain is the major pathway of energy flow whereas in the forest ecosystem, the detritus food chain is more important. In grazing chain, herbivore feed on living plant, therefore they directly affect the plant population. What they not eat is available, after death, to the decomposer. As a result, decomposers are not able to directly influence the rate of supply of their food.

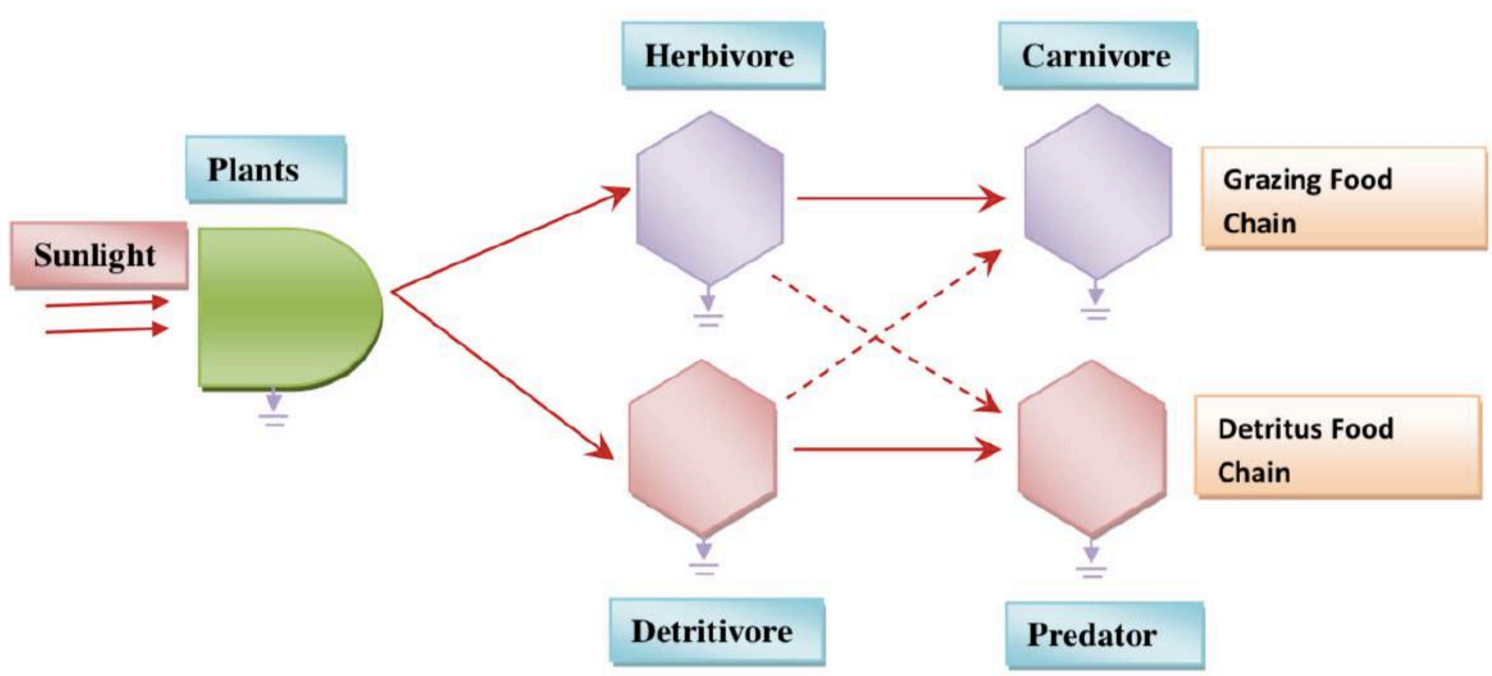


**Figure 3: Y-Shaped energy flow model showing linkage between grazing and detritus food chain.**

In heavily grazed grassland, 50% or more of the net production may pass down the grazing pathway but many aquatic systems like shallow water operated as detritus system. Since all the food is not assimilated by the grazers, some is diverted to the detritus route. So the impact of grazers on the community depends on the rate of removal of living plant and the amount of energy in the food that is assimilated.

Marine zooplanktons commonly graze more phytoplanktons than they can assimilate, the excess being egested to the detritus food chain. Thus energy flow along different path is dependent on the rate of removal of living plant material by herbivores as well as on the rate of assimilation in their bodies.

The Y-shaped model further indicates that the two food chains are in fact, under natural conditions, not completely isolated from one another. For example, dead bodies of small animals that were once part of grazing food chain become incorporated in the detritus food chain as do the feces of grazing food animals. The importance of two food chains may differ in different ecosystem, in some cases, grazing is more important and in others, detritus is more important.

**Universal energy flow model**

Universal model is applicable to any living component, whether a plant, animal micro- organism, or individual or population or a trophic group (Odum, E.P., 1968). It can depict the food chain as already shown in single and y-shaped energy flow diagram or bioenergetics of an entire ecosystem. It represents the energy partitioning in the individual or species population showing the living structure or biomass as a box (B) (Figure 4A) I- represents energy input which is light in case of autotrophs and food in case of heterotrophs. The usable part of the input is assimilated (A) and unusable part is not utilized (NU). A large portion of assimilated energy must always be respired (R) to provide maintenance or existence energy to keep the body functioning and repaired. A part of energy can be used for growth and reproduction (P). S is the stored energy, which is used to accept further input of energy.

The partitioning of energy between P and R is of vital importance to the individual and species. Large organisms require more maintenance energy than small one as they have more biomass to maintain. The warm blooded animals require more energy than the cold blooded animals. Predators generally must expend a large percentage of assimilated energy in respiration than herbivore, to find and overcoming the prey. The species adapted to unstable, recently derived or under populated area, generally allocate a large portion of their energy to reproduction. The species adapted to stable and more favourable habitats, allocate little energy to reproduction.

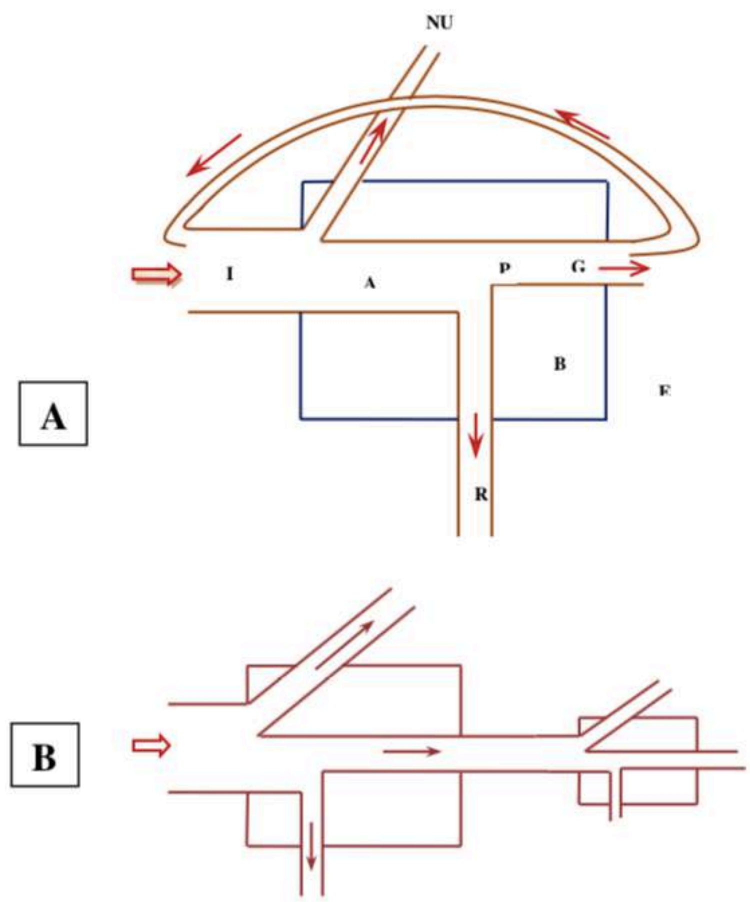


**Figure 4: Universal Energy Flow Model. I- input or ingested energy; NU- not utilized energy; A-assimilated energy; P-production; R-respiration; B-biomass; G-growth; S-stored energy; E-excreted energy (Odum, 1963).**

The universal model of energy flow can be used in two ways:
i) it can represent a species population in which case the appropriate energy inputs and the links with other species would be shown as conventional species oriented food-web diagram or
ii) the model can represent a discrete energy level in which case the biomass and energy channels represent all or parts of many population supported by the same energy source. Foxes, for example, usually obtain part of their food by eating plants (fruits etc) and part by eating herbivores (rabbit, field mice etc). A single box diagram could be used to represent the whole population of foxes if our objective is to stress intrapopulation energetic. On the other hand, two or more boxes (figure 4B) would be employed if we wish to separate the metabolism of a population into two or more trophic levels in accordance with the proportion of plant and animals consumed. These models depict the basic pattern of energy flow in the ecosystem. In practice, under natural condition, the organisms are interrelated in a way that several food chains become interlocked and this result into a complex food web.

# ECOLOGICAL EFFICIENCY

Ecological efficiency can be defined as the product of efficiencies in which organisms exploit their food resources and convert them into biomass for next higher trophic level. As biological production is almost consumed, the overall exploitation efficiency remains 100 percent, whereas, ecological efficiency is dependent on two factors: the proportion of assimilated energy incorporated in growth, storage and reproduction. The first proportion is called as assimilation efficiency and second is net production efficiency. The product of the assimilation efficiency and net production efficiencies is called as gross production efficiency. It is the proportion of food energy that is transformed into consumer biomass

energy. Net production efficiency of plants is the ratio of net production to gross production. This index varies between 30 percent and 85 percent, depending on habitat and growth form. The Rapidly growing plants in temperate zones have high net production efficiencies (75 to 85 per cent). Similar vegetation types in the tropics exhibit lower net production efficiencies, perhaps 40 to 60 per cent respiration increases relative to photosynthesis at low latitudes.

**Definition of various energetic efficiencies.**

$$\text{Exploitation efficiency} = \frac{\text{Ingestion of food}}{\text{Prey production}}$$

$$\text{Assimilation efficiency} = \frac{\text{Assimilation}}{\text{Ingestion}}$$

$$\text{Net production efficiency} = \frac{\text{Production (growth \& reproduction)}}{\text{Assimilation}}$$

$$\text{Gross Production efficiency} = \text{Assimilation efficiency} \times \text{Net production efficiency} = \frac{\text{Production}}{\text{Ingestion}}$$

$$\text{Ecological efficiency} = \text{Exploitation efficiency} \times \text{Gross production efficiency} = \frac{\text{Consumer production}}{\text{Prey production}}$$

The nutritional value of plant foods is determined by the amount of lignin, cellulose and other indigestible materials present in the plant. The animal food is more easily digested when compare with plant food. Assimilation efficiency can vary in different predatory species from 60 percent to 90 percent. The vertebrate prey species can be digested efficiently as compare to insect prey. This is because the insects have larger proportion of indigestible exoskeletons of body than the hair, feathers and scales of the vertebrates. Moreover, the assimilation efficiencies of insectivores can differ in between 70 percent to 80 percent, and most of the carnivores have about 90 percent efficiency.

In warm homeothermic (warm blooded) animals, energy is needed for maintenance, movement and heat production that otherwise could be utilized for growth and reproduction. The homeothermic animals exhibit low net production efficiency. For example birds show less than 1 percent and small mammals with high reproductive rates exhibit up to 6 percent of net production efficiency. However, sedentary poikilothermic animals (cold blooded) of aquatic species can direct up to 75 percent of their assimilated energy into the growth and reproduction. In domesticated animals, the extreme high value approaches the biochemical efficiency of egg production and tissue growth, between 70 to 80 percent (Ricklefs, 1974). The gross production efficiency (i.e., biomass production efficiency within a trophic level) is the product of assimilation efficiency and net production efficiency. Gross production efficiencies of warm-blooded terrestrial animals rarely go beyond 5 percent, and those of some birds and large mammals fall below 1 per cent. Gross production efficiencies of insects occur in between 5 to 15 percent, and those of some aquatic animals go beyond 30 per cent.

# ECOLOGICAL PYRAMID

The producers in the ecological pyramids form the base and the successive trophic levels make up the peak. Generally, the terrestrial and shallow water ecosystems show gradual leaning of pyramids as the producers remain large and characterized by buildup of organic matter. However, this trend is not always true for all ecosystems. In aquatic ecosystems such as ocean and lake, the main producers includes algae and phytoplanktons which have short- cycle, high reproductive rate and accumulate of small amount of organic matter. These producers are heavily exploited by herbivore zooplanktons. As a result, they forms inverted pyramid of biomass i.e. the base is much smaller (Producers) than the structure it supports (Herbivores).

In consecutive steps of grazing food chain the number and mass of the organisms in each step (Trophic level) is limited by the amount of energy available. As some energy is lost in the form of heat, the successive steps become progressively smaller in each transformation. This relationship is known as ecological pyramids. The ecological pyramids represent both the trophic structure as well as the trophic function of ecosystem. The ecological pyramids can be divided into three types:

**Pyramid of number**

It represents the total number of individuals at different trophic levels in the food chain. The pyramid of number was advanced by Charles Elton (1927) who explained that there is difference in the number of organisms present in each step of the food chain. The organisms present at the base of pyramid are the most plentiful. The successive trophic level of the pyramid decrease rapidly in number until there are few carnivores present at the top (figure 10A). The pyramid of number overlooks the biomass of organisms and also does not specify the energy transferred by the organisms involved. The lake ecosystem provides an example for pyramids of number. In lake ecosystem, base of the pyramid is occupied by Producers (algae, diatoms etc). These are more in numbers as compared to herbivores. The second trophic level is represented by primary consumers (Herbivores) (includes zooplanktons) which are less in number. The third trophic level is occupied by secondary consumers (primary carnivores) (includes small and medium sized fishes) which further reduced in number. The top of the pyramid is occupied by tertiary consumer (secondary carnivore) (includes large fishes) which are minimum in numbers. Thus in the pyramids of number, there is a gradual loss in the number of organisms and there is increase in the size of the body (figure 10A).

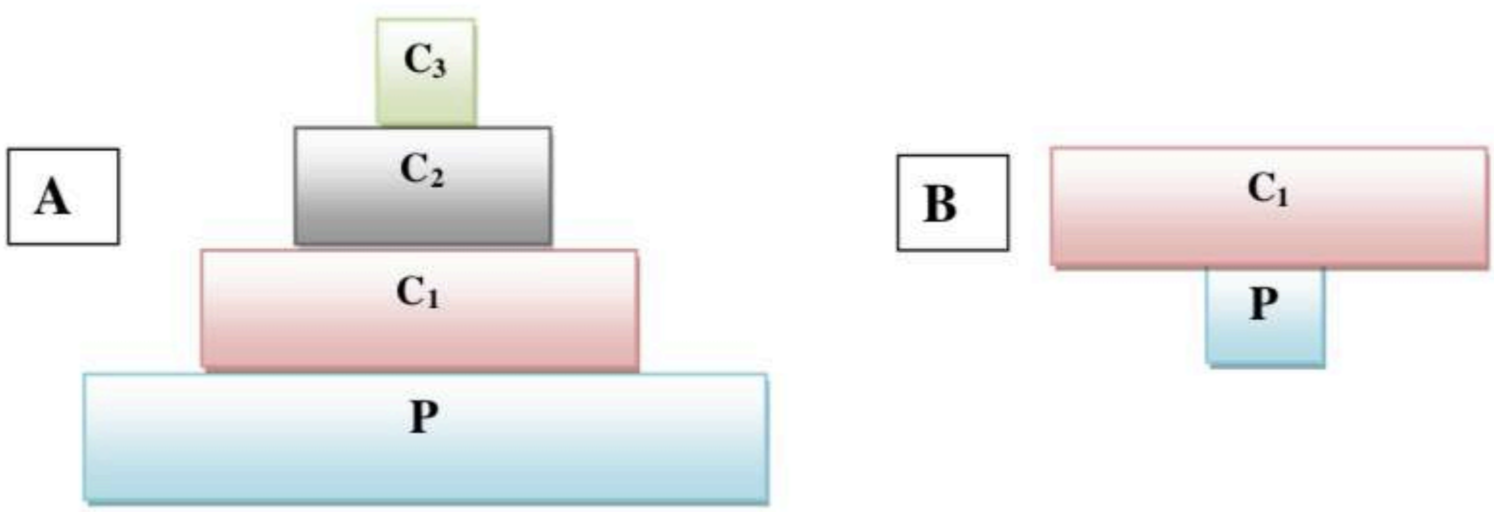


**Figure 10: Pyramid of number. A) Upright B) Inverted. (P- Producers; $C_1$-Primary consumers; $C_2$-Secondary consumers; $C_3$- Tertiary consumers).**

In the parasite food chain, the pyramid of number is reversed for the successive steps (trophic level) (figure 10B). Thus, the parasites are more in number as compare to their hosts. For example, a single tree can support large number of fruit eating birds (herbivores). These birds can support still more number of parasites such as bugs, ticks and mites.

**Pyramid of biomass**

The living weight of the organism present at any time in each trophic level forms the pyramid of biomass. Pyramid of biomass indicate gradual decrease of biomass in successive trophic level from base to top of the pyramids (figure 11A). For example, the total biomass of the producers ingested by herbivores is more than the total biomass of the herbivores in an ecosystem. Similarly, the total biomass of the primary carnivores (or secondary consumers) will be less than the herbivore and so on (figure 11A). As some amount of energy or material is lost from lower trophic level to upper trophic level, the total biomass supported at each trophic level is restricted by the rate at which energy is being stored at the next-lower level. In other words, the biomass of producers should be larger to support the herbivores. Similarly, the biomass of herbivores should be more than that of carnivores. This successive decrease of biomass from lower to upper trophic level causes narrowing of pyramid in most of the ecosystems.

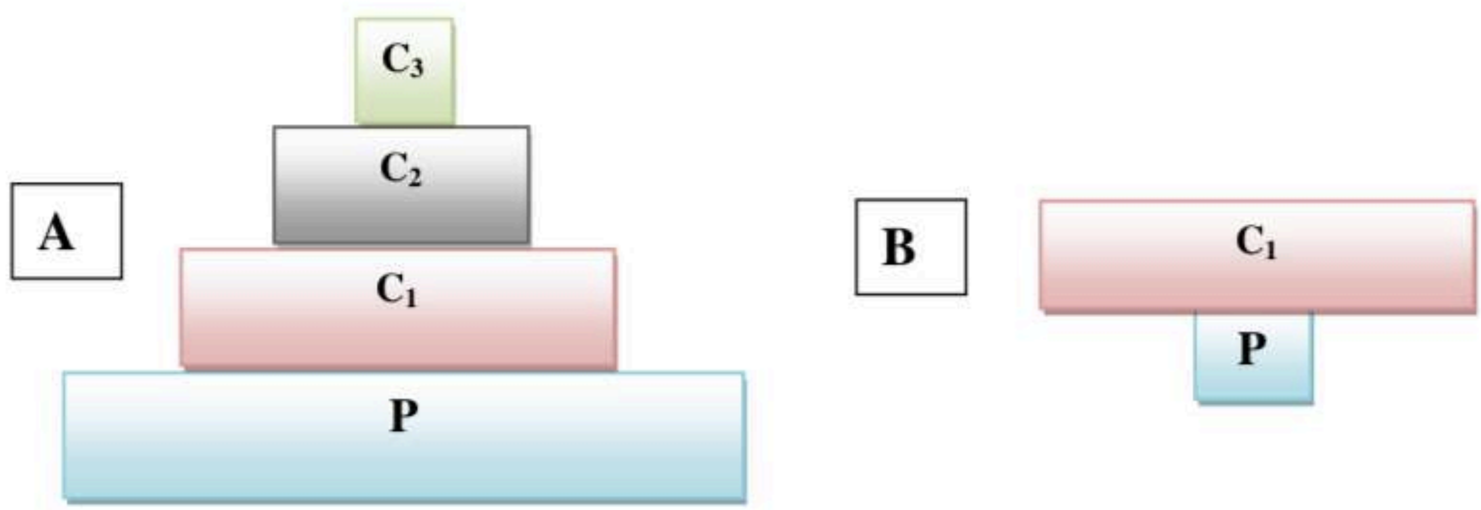


**Figure 11: Pyramid of biomass. A) Upright B) Inverted. (P- Producers; $C_1$-Primary consumers; $C_2$-Secondary consumers; $C_3$- Tertiary consumers).**

But this is not true for all ecosystems. Ecosystems such as lakes and ocean, primary productivity are restricted to phytoplanktons. They have short life cycle and fast reproduction. These phytoplanktons are heavily grazed by herbivorous (zooplanktons) which are larger in size and have longer life span. Thus, despite the high productivity of producers, they have low biomass as compared to herbivores (zooplankton). It results in an inverted pyramid, having low standing crop biomass of producers (phytoplankton) than herbivores (zooplankton). Similarly, In case of parasite like pyramid of number, the pyramid of biomass is inverted (figure 11B).

**Pyramid of energy**

It indicates the total amount of energy at each trophic level of the food chain. It also exhibits that at each trophic level loss of energy occurs due to the process of assimilation and growth (figure 12). Thus, at the producer level, total energy is more than at higher trophic level. When productivity is measured in term of energy, the pyramids specify not only the energy flow at each level, but also the actual role played by various organisms in the transfer of energy. Some organisms have smaller biomass but they assimilate and transfer more energy than that of organisms having much larger biomass.

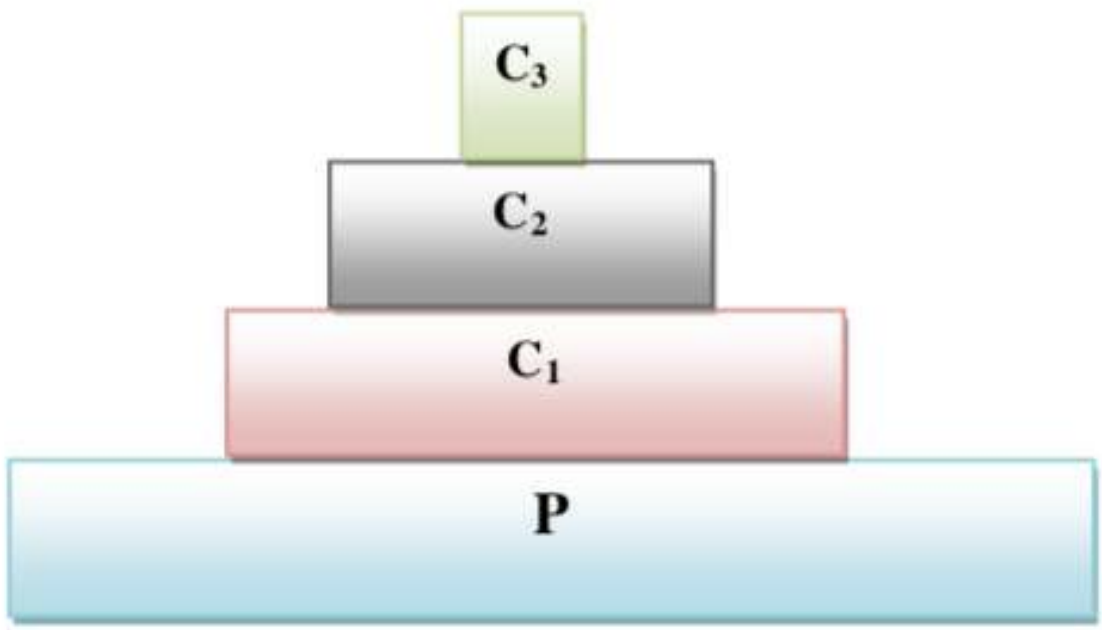


**Figure 12: Pyramid of energy**.

The pyramids of energy always show slopping because there is always declining of transferred energy from one trophic level to other (figure 12). In the open water communities, the producers have less biomass than consumers but they store and transfer more energy than that of the next level. The high energy flow is maintained by a rapid turnover of individual plankton, instead of increase of total mass.

# SUMMARY

An organism in the nature is always connected with individuals of its own species and of different species along with their physical and chemical environment. In ecosystem, all biotic and abiotic component of the environment are connected through energy flow and nutrient cycle. It bears all biological and physical components that are essential for the survival. An ecosystem can be natural or artificial, temporary or permanent and large or small.

The natural ecosystems do not have separate boundaries. An ecosystem progressively combines with the adjacent one through a transitional zone called as ecotone. It has more population density of certain species than either of the adjoining communities. This phenomenon is known as edge effect.

In an ecosystem, flow of energy occurs through a series of organisms by eating and being eaten by another organism comprises a food chain. The Food chain is simple when it has only one trophic level besides the decomposers like Eichhornia in Eutrophic pond. It became complex when it bears both producer and consumer levels. Food chain can be categorized as grazing food chain and detritus food chain. The grazing food chain begins with producers which produces their food by the process of photosynthesis and then moves through herbivores to carnivores. It is directly influenced by influx of the radiant energy from sun. The detritus food chain begins with the dead organic wastes and matters which are derived from the grazing food chain are known as detritus. The energy contained in the detritus is utilized by a group of organisms called detritivores that are separate from the grazing food chain. In nature, food chains are not isolated sequences but are interconnected with each other and make an interlocking pattern. The same organism may operate in the ecosystem at more than one trophic level. Thus in a given ecosystem various food chains are linked together and interrelated with each other to form a complex network called food web.

In consecutive steps of grazing food chain the number and mass of the organisms in each trophic level is limited by the amount of energy available. As some energy is lost in the form of heat, the successive steps become progressively smaller in each transformation. This relationship is known as ecological pyramids.

**The pyramid of number** represents the total number of individuals at different trophic levels in the food chain. The organisms present at the base of pyramid are the most plentiful. The successive trophic level of the pyramid decrease rapidly in number. In the parasite food chain, the pyramid of number is reversed for the successive steps.

**Pyramid of biomass** represents the living weight of the organism present at any time in each trophic level. Pyramid of biomass indicates gradual decrease of biomass in successive trophic levels. In case of parasite like pyramid of number, the pyramid of biomass is inverted.

**Pyramid of energy** indicates the total amount of energy at each trophic level of the food chain. The pyramids of energy always show slopping because there is always declining of transferred energy from one trophic level to other.