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Topic: Energy Flow in Ecosystem - Productivity

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ENERGY FLOW IN ECOSYSTEM - PRODUCTIVITY

This energy flow from sun to producer and producers to consumers is depicted in terms of productivity or energy efficient of an ecosystem. The relationship between the amount of energy accumulated and the amount of energy utilized within one trophic level of food chain has an important bearing on how much energy from one trophic level passes on to the next trophic level in the food chain. The ratio of output of energy to input of energy is referred to as **ecological efficiency**. There are different kinds of ecological efficiency that can be measured by following parameters:

- Ingestion which indicates the quantity of food or energy taken by trophic level. This is also called exploitation efficiency.
- Assimilation indicates the amount of food absorbed and fixed into energy rich organic substances which are stored or combined with other molecules to build complex molecules such as proteins, fats etc.
- Respiration which indicates the energy lost in metabolism.

Productivity, in general, is the rate at which energy is added to the bodies of a group of organisms in the form of biomass, whereas **gross productivity** is the overall rate of energy capture, and **net productivity** is the minus product of gross productivity and energy consumed. The productivity may be of different kinds such as primary productivity and secondary productivity.

Primary productivity

As described above, the fraction of fixed energy a trophic level passes on to the next trophic level is called production. Green plants fix solar energy and accumulate it in organic forms as chemical energy. Since it is the first and basic form of energy storage, the rate at which the energy accumulates in the green plants or producers is known as primary productivity.

The amount of organic matter present at a given time per unit area is called standing crop or biomass which is usually expressed as dry weight in g/m^2 or kg/m^2 or t/ha or 10^{6}g/hectare, whereas primary productivity is the rate at which energy is bound or organic material is created by photosynthesis per unit area of earth's surface per unit time. It is most often expressed as energy in calories/cm^2/yr or dry organic matter in g/m^2/yr (g/m^2 $\times$ 8.92 = lb/acre). The total solar energy trapped in the food material by photosynthesis is referred to as gross primary productivity (G.P.P.), while the amount of energy bound in organic matter per unit area and time is left after respiration in plants is called as net primary production (N.P.P.) or plant growth. Only the net primary productivity is available for harvest by man and other animals.

$$\boldsymbol{Net\ productivity = (Gross\ productivity)\ - (Energy\ lost\ in\ respiration)}$$

Secondary productivity: It is the rates at which the heterotrophic organisms resynthesize the energy-yielding substances. Secondary productivities are the productivities of animals and saprobes in communities. The amount of energy stored in the tissues of consumers or heterotrophs is termed as net secondary production and the total plant material ingested by herbivores is grass secondary production. Total plant material ingested by herbivores minus the materials lost as faeces is equal to ingested secondary production.

Whether it is primary production or secondary production, they vary depending upon several environmental factors. These environmental factors are as follows:

- Solar radiation and temperature
- Moisture – Leaf water potential, soil moisture and precipitation, fluctuation and transpiration.
- Mineral nutrition – Uptake of mineral from the soil, rhizosphere effects, fire effects, salinity heavy metals, nitrogen metabolism.
- Biotic activities – Grazing, above ground herbivores, below ground herbivores, predators and parasites, disease of primary producers.
- Impact of human populations – Pollutions of different sorts, ionizing radiations like atomic explosions, etc.

As described above, there are three fundamental concepts of productivity, for example, standing crops, materials removed, and production rate.

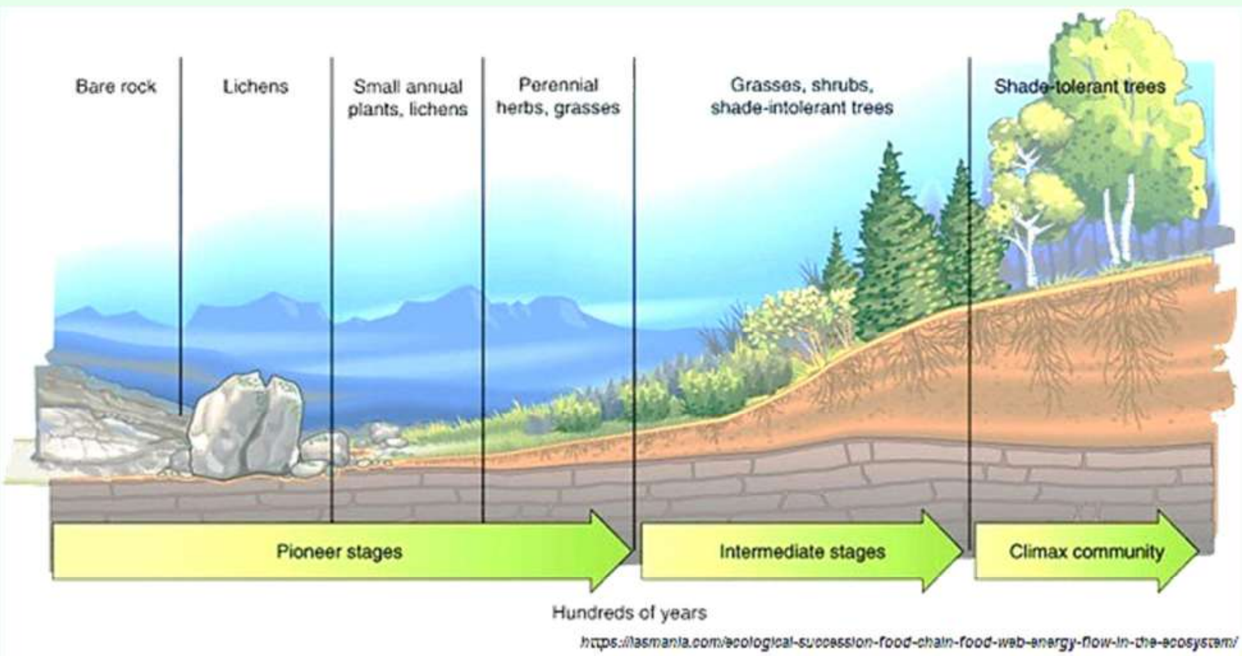
1. **Standing crop:** It is the abundance of the organisms existing in the area at any one time. It may be expressed in terms of number of individuals, as biomass of organisms, as energy content or in some other suitable terms. Measurement of standing crop reveals the concentration of individuals in the various populations of ecosystem.
2. **Materials removed:** The second concept of productivity is the materials removed from the area per unit time. It includes the yield to man, organisms removed from the ecosystem by migration, and the material withdrawn as organic deposit.
3. **Production rate:** The third concept of productivity is the production rate. It is the rate at which the growth processes are going forward within the area. The amount of material formed by each link in the food chain per unit of time per unit area or volume is the production rate.

All the three major groups of organisms viz. producers, consumers and reducers (decomposers) are the functional kingdoms of natural communities. The three represent major directions of evolution and are characterized by different modes of nutrition. Plants feed primarily by photosynthesis, animals feed primarily by ingesting food that is digested and absorbed in the alimentary canal and the saprobes feed by absorption and have need for an extensive surface of absorption. The principal kinds of organisms among saprobes are the unicellular bacteria, yeasts, chytrids or lower fungi and higher fungi with mycelial bodies which fed upon as much as 90% of net primary production that remains un-harvested, and therefore these saprobes have a larger and more essential role than other organisms in degrading dead organic matter to inorganic forms and thus disperse back to the environment. It is the reason why secondary production by reducers i.e. decomposers, exceed that by consumers; however the biomass of decomposers are more difficult to measure. However, it can be easily observed that even small masses of decomposers decompose or degrade and transform larger masses of organic matter to inorganic remnants.

A community or ecosystem, like an organism, is an open energy system. The continuous intake of energy in photosynthesis replaces the energy dissipated to environment by respiration and biological activity and the system does not run-down through the loss of free energy to maximum entropy. If the amount of energy entrapped is greater than the energy dissipated, the pool of biologically useful energy of organic bonds increases. This results in increase of community biomass and consequently the community grows; such is the case in succession, known as **ecological succession**. If energy intake is lesser than energy dissipation, the community biomass will decrease and it must, in some sense, retrogress. If energy intake and loss are in balance, the pool of organic energy is in steady state; such is the case in **climax communities**.

There are two types of succession in an ecosystem; primary succession and secondary succession, which are as follows;

1. **Primary succession:** Primary succession is one of two types of biological and ecological succession of plant life, occurring in an environment in which new substrate devoid of vegetation and other organisms usually lacking soil, such as a lava flow or area left from retreated glacier, is deposited.
    - From a pioneer community (initiation) to a climax community (Final)
    - Rare & takes a long time to generate



2. **Secondary succession:** Development of a community which forms after the existing natural vegetation that constitutes a community is removed, disturbed or destroyed by a natural event like hurricane or forest fire or by human related events like tilling or harvesting land. It is relatively fast as, the soil has the necessary nutrients as well as a larger pool of seeds and other dormant stages of organisms.

There are three aspects of this steady state, which are as follows;

1. The steady state of population of climax communities in which equal birth and death rates in population keep the number of individuals relatively constant,
2. The steady state of energy flow,
3. The steady state of the matter of community, where addition of material by photosynthesis and organic synthesis is balanced by loss of material through respiration and decomposition.

Methods of Measuring Primary Production

There are several parameters for measuring primary production and the methods of measuring primary production are based on those parameters. Different methodology of measuring primary production is discussed here as;

Harvest method: It involves removal of vegetation periodically and weighing the material. For measuring above ground production, the above ground plant parts are clipped at ground level, dried to constant weight at 80°C and weighed. The dry weight in g/m^2 /year gives the ground production. Below ground production is estimated by using frequent core sampling technique developed by Dahlman and Kucera in 1965. It is expressed in terms of weight in gm per unit area per year. In terms of energy one gm dry weight of plant material contains 4 to 5 kcal. However, there are some limitations of this method which are as follows:

- The amount of plant material consumed by herbivores and the food oxidized during respiration process of the plants is not accounted.
- Root biomass is neglected.
- Photosynthetic products translocated to underground parts of plants are not known.

In spite of these limitations the method is used all over for measuring net assimilation rate (NAR) and relative growth rate (RGR).

Carbon dioxide assimilation method: Utilization of CO_2 in photosynthesis or its liberation during respiration is measured by infrared gas analysis or by passing the gas through Baryta water $Ba(OH)_2$ and titrating the same. The CO_2 removed from incoming gas chamber is taken to be synthesized into organic matter by the green plants. Performing the experiment in light and dark chambers the net and gross production can be measured.

In the lighted chamber photosynthesis and respiration take place simultaneously and the CO_2 coming out from the chamber is the unused gas of the atmosphere plus gas from the respiration of plant parts. In the dark chamber all CO_2 is due to respiration.

$$\boldsymbol{Net\ productivity = (Gross\ productivity)\ - (Energy\ lost\ in\ respiration)}$$

Oxygen production method: In the aquatic vegetation, CO_2 gas analysis method is not used but oxygen evolution method is generally used. The light and dark bottle technique is employed for measuring primary production of aquatic plant. In this method, two bottles, one transparent and the other opaque are filled with water at a given depth of lake, closed, maintained at that depth for some time and then brought to laboratory for determination of oxygen content in the water.

The decrease of oxygen in dark bottle is due to respiratory activity while increase of O_2 in light bottle is due to photosynthesis. The total increase of O_2 in light bottle plus the amount of O_2 decreased in dark bottle express gross productivity (O_2 value multiplied by 0.375 gives an equivalent of carbon assimilation). Recently, oxygen electrodes have been used for estimating oxygen content in water.

$$\boldsymbol{Carbon\ assimilation = 0.375 \times O_2\ value}$$

Chlorophyll method: The amount of chlorophyll/m^2 is almost limited to a narrow range of 0.1 to 3.0 gm regardless of the age of individuals or the species present therein. There is direct correlation between the amount of chlorophyll and dry matter production in different types of communities with varying light conditions.

The relation of total amount of chlorophyll to the photosynthetic rate is referred to as assimilation ratio or rate of production/gm chlorophyll. Total chlorophyll per unit area is greater in land plants as compared to that in aquatic plants. In marine ecosystem the rate of carbon assimilation is 3.7 g/ hr/g of chlorophyll. The relationship between area based chlorophyll and dry matter production in terrestrial ecosystems has been worked out by Japanese ecologists Argua and Monsi (1963). However, it is conceptualized and propounded by Gesner in 1949.

Other methods: Pandeya (1971), Sharma (1972) and several other ecologists have evolved correlation coefficients for evaluating biomass and productivity in forest trees by measuring their diameter at breast height (DBH), height, canopy cover, etc. For this, a regression analysis is carried and methods of which are as follows;

- Diameter of trees in sample quadrats is measured at breast height and the height repeated is determined for each tree.
- Different diameter and height classes are determined for each species.
- A set of sample trees are cut and subjected to a detailed analysis for dry weight of stems, twigs, leaves and roots.
- Regression values are computed for the sets of trees belonging to each girth class, relating the biomass of each fraction to the diameter at breast height.
- The regression values are used to compute the probable biomass and Production each tree in the sample area. These values for each species when pooled give biomass and production rate of trees per unit area in the forest. Age of the trees markedly influences the annual net production.

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