ECOLOGICAL PYRAMIDS & ENERGY FLOW IN ECOSYSTEM

Introduction

'Ecology' is the scientific analysis and study of interactions between organisms and their environments. It is an interdisciplinary area that includes biology, geography and Earth science. Ecological pyramids show the relative amount of energy or matter contained within each trophic level in a given food chain or food web. Trophic level is a hierarchial position of an organism in an ecosystem. Ecological pyramids begin with producers on the bottom (like plants) and proceed through the various trophic levels (like herbivores that eat plants, then carnivores that eat herbivores, then carnivores that eat other carnivores, and so on). The highest level is the top of the food chain.

There is a relationship between the numbers, biomass and energy contents of the producers and consumers of different orders in any ecosystem. Diagrammatic representation of these relationships is referred to as 'ecological pyramids'. The ecological pyramids are of four types viz; pyramid of numbers, pyramid of biomass, pyramid of energy and pyramid of productivity.

Food Chain & Food Web:

The concept of food chains was first introduced by Al-Jahiz in the 9th century and later introduced in the book "Animal Ecology", published in 1927 by Charles Elton. Elton also introduced the concept of a food web in this book.

A food chain is different from a food web. A Food chain is a model that shows flow of energy and nutrients from one organism to another organism in an ecosystem. It is a linear network of links starting from producer organisms like grass or trees which use sunlight to make their food and ending at apex predator species such as grizzly bears or killer whales, detritivores like earthworms or woodlice, or decomposers like fungi or bacteria. A food chain shows how the organisms are related to each other by the food they consume. Each level of a food chain represents a different trophic level. The length of a food chain depends upon the number of organisms. On the other hand a Food web or food cycle is the connection between food chains and what species eats in an ecological system. A common metric used to quantify food web trophic structure is the length of the food chain. In its simplest form, the length of a food chain is ‘the number of links between a trophic consumer and the base of the food web’. The mean food chain length of an entire food web is the ‘arithmetic average of the lengths of all chains in a food web’.

The length of a food chain is a continuous variable. It provides a measure of the passage of energy and an index of the ecological structure. The energy increases progressively through the linkages in a linear fashion from the lowest to the highest feeding levels. Food chains can be used in ecological modelling. Food chains are simplified abstractions of food webs, but they are complex in their dynamics and mathematical implications. Food chain studies have an important role in ectotoxicology studies. They can be used in tracing the pathways and biomagnifications of environmental contaminants.

Food chains can be varied in length from three to six or more levels. ‘Producers’, such as plants, are organisms that utilize solar or chemical energy to synthesize food. Producers comprise the base of the food chain. The condition is different in the deep sea, where, food chains are centered on hydrothermal vents and cold seeps which exist in the absence of sunlight. Chemosynthetic bacteria and archea use hydrogen sulfide and methane from hydrothermal vents and cold seeps as an energy source to produce carbohydrates. ‘Consumers’ are organisms that eat other organisms. All organisms except the first organisms present at the base of chain are consumers.

A ‘food web’ or ‘food cycle’ is the natural interconnection of food chains. Another name for ‘food web’ is a ‘consumer-resource system’. All life forms can be divided into two categories like autotrophs and heterotrophs. ‘Autotrophs’ produce organic matter from inorganic substances like minerals and gases like carbon dioxide. The organic matter is required to maintain their bodies, develop and to reproduce. There is a gradient between trophic levels which consists of complete autotrophs, mixotrophs and complete heterotrophs. ‘Complete autotrophs’ are dependent on atmospheric carbon; ‘mixotrophs’ are autotrophic organisms that partially utilize organic matter other than atmosphere, while ‘complete heterotrophs’ obtain energy from autotrophs. There are various kinds of feeding relations that can be divided into herbivory, carnivory, scavenging and parasitism .

Ecological Pyramids

An ecological pyramid, also known as trophic pyramid, eltonian pyramid, energy pyramid, or sometimes food pyramid, is a graphical representation designed to show the biomass or bio productivity at each trophic level in a given ecosystem.

Ecological pyramids can be differentiated on four basis:

- Pyramid of Numbers
- Pyramid of Biomass
- Pyramid of Energy, and
- Pyramid of Productivity

Pyramid of Numbers:

The first attempt to provide a quantitative law concerning the trophic levels was made by Charles Elton in 1927 when he coined the term 'pyramid of numbers'. The 'pyramid of numbers' is focused on the relationship between the numbers of primary producers and consumers of different orders. The base of such a pyramid always represents the numbers of primary producers. The subsequent structures on this base are represented by the number of consumers of successive levels. The top of the pyramid represents the number of top carnivores in that ecosystem. In the ecological pyramid so formed, the higher the step in the pyramid, the lower the number of individuals and the larger their size. The shape of the pyramid of numbers may be upright or inverted. In an upright cropland ecosystem, the numbers of crop plants at the base of the pyramid are very large; the numbers of grasshoppers are usually less than the numbers of green plants; numbers of

frogs is less than the number of grasshoppers and finally the number of top carnivores is the least in the series of organisms forming a food chain. But in an inverted pyramid of numbers, the number of primary consumers (i.e. herbivorous birds feeding upon the tree fruits) is always greater than the number of primary producers (a tree), and the number of parasites living and feeding upon the bird's body is still greater.

Pyramid of Biomass:

Biomass is the amount of living or organic matter present in an organism. Biomass pyramids show how much biomass is present in the organisms at each trophic level.

A pyramid of biomass takes into account the unit area utilized, the biomass of the producers, the biomass of the herbivores, the biomass of the first-level carnivores, and so on. Pyramids of biomass can be either vertical or inverted. There are two types of ecosystems, where the pyramid of biomass is upright . The biomass of a single tree is naturally very high than the biomass of a number of birds feeding upon the tree. Also, the biomass of even a very large number of bird parasites is lesser than that of the birds. Therefore, in upright pyramid the biomass decreases with successive trophic levels.

On the other hand, the pyramid of biomass is inverted if the number of organisms in the particular tropic level are considered. In a lake or pond ecosystem, the biomass of diatoms and other phytoplankton is quite negligible as compared with that of the crustaceans and small herbivorous fish that feed on these producers. The biomass of large carnivorous fish

living on small fishes is quite greater. In fact, this is the condition in most aquatic ecosystems, including the sea.

Pyramid of Energy:

The flow of energy in a pyramid of energy is from one trophic level of a community to the next. The shape of pyramid of energy is always upright or triangular because in this case the time factor is always taken into account. The pyramid of energy represents the total amount of energy utilized by different trophic level organisms of an ecosystem in a limited area over a set period of time. It is usually per square metre per year. This shows that the quantity of energy trapped by green plants is highest among organisms of different trophic levels and, therefore, the base of the pyramid is broad. As in case of an aquatic ecosystem, the large numbers of phytoplankton quickly complete their life cycles. Sets of new populations or crops of phytoplankton are formed every few hours or days. Thus, the cumulative energy contents trapped by these generation after generation of phytoplankton in the course of a year is certainly much more than that trapped by only a few generations of herbivorous fishes in the corresponding time and space. The energy content trapped by the carnivores living on the herbivorous organisms is the least. Therefore, the pyramid of energy can never be inverted. This follows directly from the first law of thermodynamics, “the law of conservation of energy”, which states that ‘energy can neither be created nor destroyed; rather, it can transform from one form to another’. If primary organisms of any trophic level are destroyed, the organisms of the higher trophic level will automatically perish for the need of food or source of energy and ultimately the upright pyramidal shape is maintained.

In 1957, H.T. Odum collected the energy contents of different trophic level organisms. He did so over a period of one year to make an upright pyramid. According to his observations, the energy content from primary producers was calculated as 208,010 kcal/m/yr. It decreased to 3368 kcal/m/yr in consumers of first order, to 383 kcal/m/yr in consumers of second order and further to 21kcal/m/yr in consumers of third order. Thus, a top carnivore needs a very broad base of green plants equivalent to 208010 kilo calories of energy. This amount of energy is required for the organic production of only 21 kilo calories of energy. The ratio of energy intake and energy of the produced biomass i.e., of input and output is called the 'ecological efficiency'. This can be studied at any trophic level. However, in 1976, James O Farlow used the principle of pyramid of energy to answer the question of whether or not dinosaurs were poikilothermic. A 'poikilothermic organism' is one whose internal body temperature varies considerably. It is the opposite of a 'homeothermic organism', which can maintain thermal homeostasis.

Pyramid of Productivity

Ecological pyramid of productivity shows the production or turnover of biomass at each trophic level. Instead of showing a single snapshot in time, productivity pyramids show the flow of energy through the food chain. Typical units of productivity are grams per meter square per year or calories per meter square per year.

When an ecosystem is healthy, this graph produces a standard ecological pyramid. This is because in order for the ecosystem to sustain itself, there must be more energy at lower trophic levels than there is at higher trophic

levels. This allows organisms on the lower levels to not only to maintain a stable population, but also to transfer energy up the pyramid. The exception to this generalization is when portions of a food web are supported by inputs of resources from outside the local community. In small, forested streams, for example, the volume of higher levels is greater than could be supported by the local primary production.

In 1995, Pauly and Christensen showed that when energy is transferred to the next trophic level, typically only 10% of it is used to build new biomass, and becomes stored energy. The rest goes to the metabolic processes. Therefore, in the pyramid of productivity each step will be 10% the size of the previous step like 100,000, 10,000, 1,000, 100, 10, 1, 0.1 and 0.01).

There are several advantages of the pyramid of productivity.

1. It takes account of the rate of production over a period of time.
2. Two species of comparable biomass may have very different life spans. Thus, a direct comparison of their total biomasses is misleading but their productivity is directly comparable.
3. The relative energy chain can be compared using pyramids of energy.
4. There are no inverted pyramids.
5. The input of solar energy can be added.

The pyramid of productivity also has some disadvantages.

1. The rate of biomass production of an organism is required, which involves measuring growth and reproduction through time.
2. There is difficulty in assigning organisms to a specific trophic level, specially the decomposers and detritivores.

Despite this, productivity pyramids usually provide more insight into an ecological community when the information required is available.

Material Flux and Recycling

Many of the Earth's elements and minerals are contained within the tissues and diets of organisms. Therefore, mineral and nutrient cycles generally trace food web energy pathways. Stoichiometry can be employed to analyze the ratios of the main elements found in all organisms like carbon (C), nitrogen (N) and phosphorus (P). There is a large transitional difference between many terrestrial and aquatic systems as Carbon:Phosphorus and Carbon:Nitrogen ratios are higher in terrestrial systems while Nitrogen:Phosphorus ratios are equal between the two systems. Mineral nutrients are required for growth, development, and vitality in an organism. Food web shows the pathways of mineral nutrient cycling as they flow through organisms. Most of the primary production in an ecosystem is not consumed, but is recycled by detrivorous organisms back into useful nutrients. Many of the microorganisms are involved in the formation of minerals in a process called ‘biomineralization’. Bacteria that live in detrital sediments create and recycle nutrients and biominerals. Earlier food web models and nutrient cycles were treated separately, but there is a strong functional connection between the two in terms of stability, flux, sinks, sources, and recycling of mineral nutrients

Conclusion

An ‘ecological pyramid’ is a graphical model of energy flow in a community. The different trophic levels represent different groups of organisms that might compose a food chain. In some food chains, there is a fourth

consumer level, and, rarely, a fifth. It is noteworthy, that an ecological pyramid's shape shows how the amount of useful energy decreases as it is used by the organisms in that level. Also, the energy that enters a community is ultimately lost to the living world as heat. So, we can see how deeply life and energy are connected with each other and how they work together to maintain the balance of the ecosystem.

GLOSSARY

1. Abiotic =Something which is non-living.
2. Abundance =The number of organisms in a given population.
3. Adaptation = How living things change what they do or what they are to survive in a particular environment. In this the organism is not a passive recipient of external circumstances; the relationship is interactive.
4. Biomass =The total quantity of living matter in a given area or ecosystem.
5. Community Coefficient = A measure of similarity between the plants and animals of two different ecological communities.
6. Consumer =An organism that consumes other organisms, whether living or dead.
7. Decomposer =An organism that eats dead organic matter. Most are bacteria, algae and fungi. They fuel the nitrogen and oxygen cycles that support all life on Earth.
8. Detritus = Decomposing organic matter (leaves, bugs, etc.).

9. Ecosystem = A biotic community and its surroundings, part inorganic (abiotic) and part organic (biotic), the latter including producers, consumers and decomposers.
10. Food Chain =The path of food energy transfer from green plants (primary producers) to grazers (primary consumers), omnivores and carnivores (secondary consumers), and to their predators (top carnivores). The detritus food chain starts when organic matter settles on the ground and breaks down.
11. Food Web = The interconnection of all food chains in an ecosystem. Food web diagrams emphasize the circular complexity of feeding relationships.

FAQ's

Q1: What is an energy pyramid?

An energy pyramid is a graphical model of energy flow in a community. The different levels represent different groups of organisms that might compose a food chain. From the bottom-up, they are as follows:

Producers — bring energy from nonliving sources into the community

Primary consumers — eat the producers, which makes them herbivores in most communities

Secondary consumers — eat the primary consumers, which makes them carnivores

Tertiary consumers — eat the secondary consumers

Q2: Why are energy pyramids shaped the way they are?

An energy pyramid's shape shows how the amount of useful energy that enters each level — chemical energy in the form of food — decreases as it is used by the organisms in that level. As cell respiration "burns" food to release its energy, and in doing so, produces ATP, which carries some of the energy as well as heat, which carries the rest. ATP is then used to fuel countless life processes. The consequence is that even though a lot of energy may be taken in at any level, the energy that ends up being stored there which is the food available to the next level is far less. Scientists have calculated that an average of 90% of the energy entering each step of the food chain is "lost" this way (although the total amount in the system remains unchanged). The consumers at the top of a food pyramid, as a group, thus have much less energy available to support them than those closer to the bottom. That's why their numbers are relatively few in most communities. Eventually, the amount of useful energy left can't support another level. That's why energy flow is depicted in the shape of a pyramid. The energy that enters a community is ultimately lost to the living world as heat.

Q3: How many trophic levels are in the food chain?

All food chains and webs have at least two or three trophic levels. Generally, there are a maximum of four trophic levels. Many consumers feed at more than one trophic level. Humans, for example, are primary consumers when they eat plants such as vegetables.

Q4: Why is the pyramid of biomass inverted?

The English Channel ecosystem exhibits an inverted biomass pyramid since the primary producers make up less biomass than the primary consumers. Pyramid ecosystem modeling can also be used to show energy

flow through the trophic levels; pyramids of energy are always upright since energy decreases at each trophic level.

Q5: Why are some ecological pyramids not a typical pyramid shape?

Ecological pyramids can also be called trophic pyramids or energy pyramids. Pyramids of numbers can be either upright or inverted, depending on the ecosystem. A typical grassland during the summer has an upright shape since it has a base of many plants, with the numbers of organisms decreasing at each trophic level .