ENERGY FLOW IN ECOSYSTEM

BY

DR. POULAMI ADHIKARY MUKHERJEE
ASSISTANT PROFESSOR
DEPARTMENT OF ZOOLOGY
NARAJOLE RAJ COLLEGE

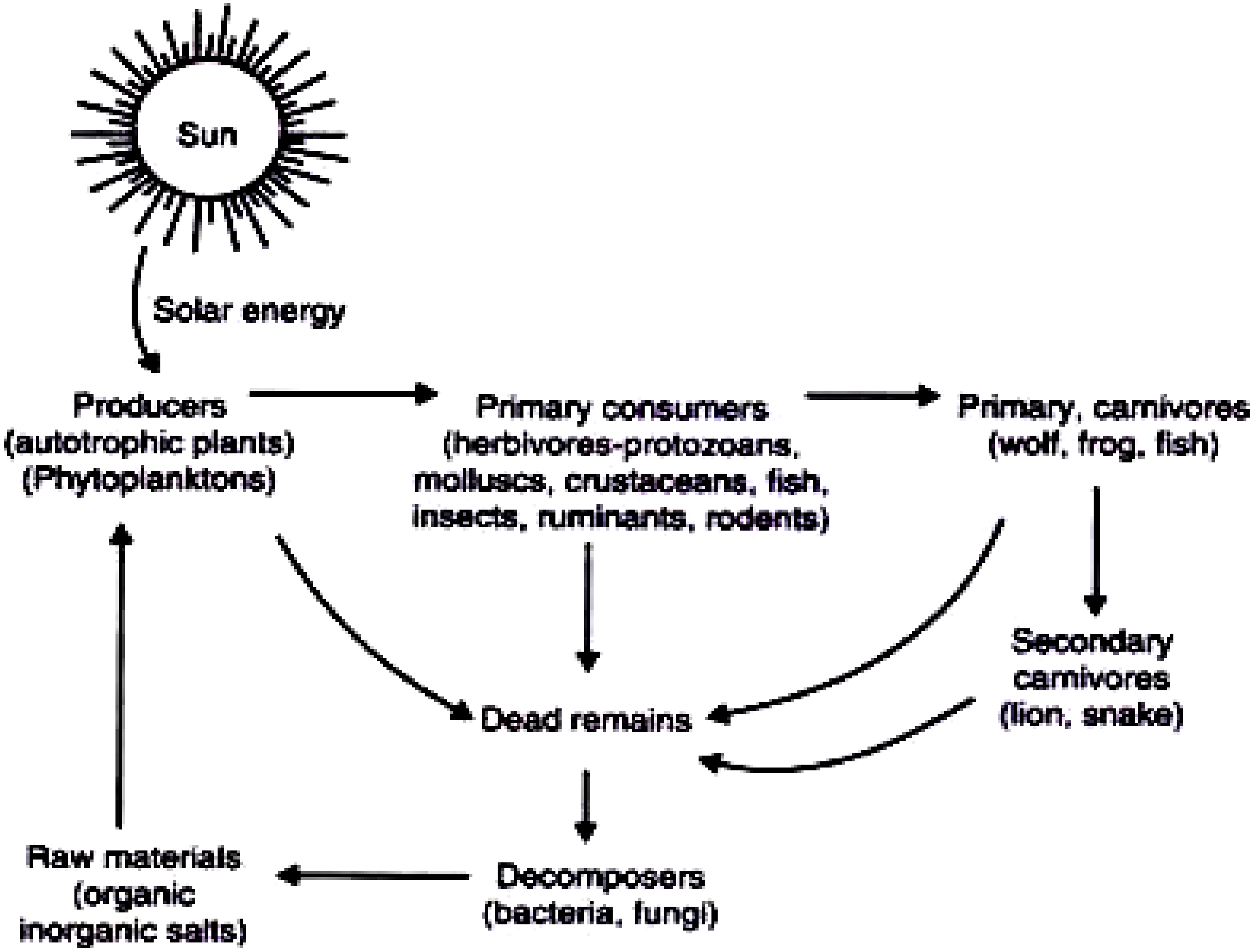
Energy Flow in Ecosystem:

The chemical energy of food is the main source of energy required by all living organisms. This energy is transmitted to different trophic levels along the food chain. This energy flow is based on two different laws of thermodynamics:

- **First law of thermodynamics**, that states that energy can neither be created nor destroyed, it can only change from one form to another.

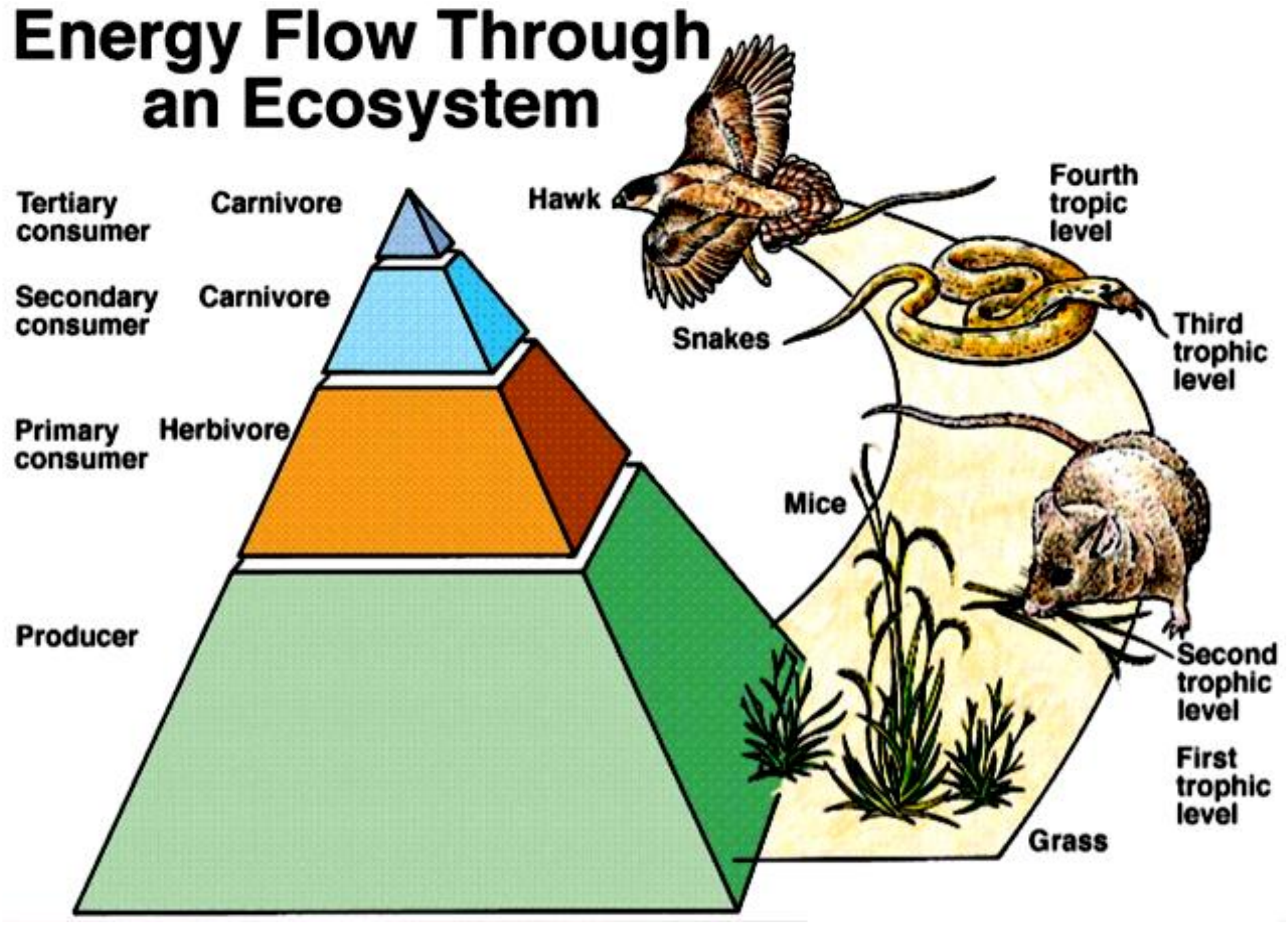
- **Second law of thermodynamics**, that states that as energy is transferred more and more of it is wasted. It establishes the concept of entropy as a physical property of a thermodynamic system.

The energy flow in the ecosystem is one of the major factors that support the survival of such a great number of organisms. The energy flow is the amount of energy that moves along the food chain. This energy flow is also known as calorific flow. For almost all organisms on earth, the primary source of energy is solar energy. It is amusing to find that we receive less than 50 per cent of the sun's effective radiation on earth. When we say effective radiation, we mean the radiation, which can be used by plants to carry out photosynthesis. Energy flow is the flow of energy through living things within an ecosystem. The energy flow in the ecosystem is important to maintain an ecological balance. The producers synthesise food by the process of photosynthesis. A part of the energy is stored within the plants. The remaining energy is utilised by the plants in their growth and development. This stored energy is transferred to the primary consumers when they feed on the producers. This energy is further passed on to the secondary consumers when they feed on the primary consumers, and so on. All living organisms can be organized into producers and consumers, and those producers and consumers can further be organized into a food chain. Each of the levels within the food chain is a trophic level. In order to more efficiently show the quantity of organisms at each trophic level, these food chains are then organized into trophic pyramids. The arrows in the food chain show that the energy flow is unidirectional, the head of the arrows show the direction energy is moving in, and that energy is lost as heat at each step along the way.



Flow of energy at different levels of ecosystem.

The unidirectional flow of energy and the successive loss of energy as it travels up the food web are patterns in energy flow that are governed by Thermodynamics, which is the concept of energy exchange between systems. Trophic dynamics relates to Thermodynamics because it deals with the transfer and transformation of energy (originating externally from the sun via solar radiation) to and among organisms.


Energy Flow Through an Ecosystem
Tertiary consumer
Carnivore
Secondary consumer
Carnivore
Primary consumer
Herbivore
Producer
Hawk
Snakes
Mice
Grass
Fourth tropic level
Third trophic level
Second trophic level
First trophic level

Most of the sun's radiation that falls on the earth is usually reflected back into space by the earth's atmosphere. This effective radiation is termed as the Photosynthetically Active Radiation (PAR).

Overall, we receive about 40 to 50 percent of the energy having Photosynthetically Active Radiation and only around 2-10 percent of it is used by plants for the process of photosynthesis. Thus, this percent of PAR supports the entire world as plants are the producers in the ecosystem and all the other organisms are either directly or indirectly dependent on them for their survival.

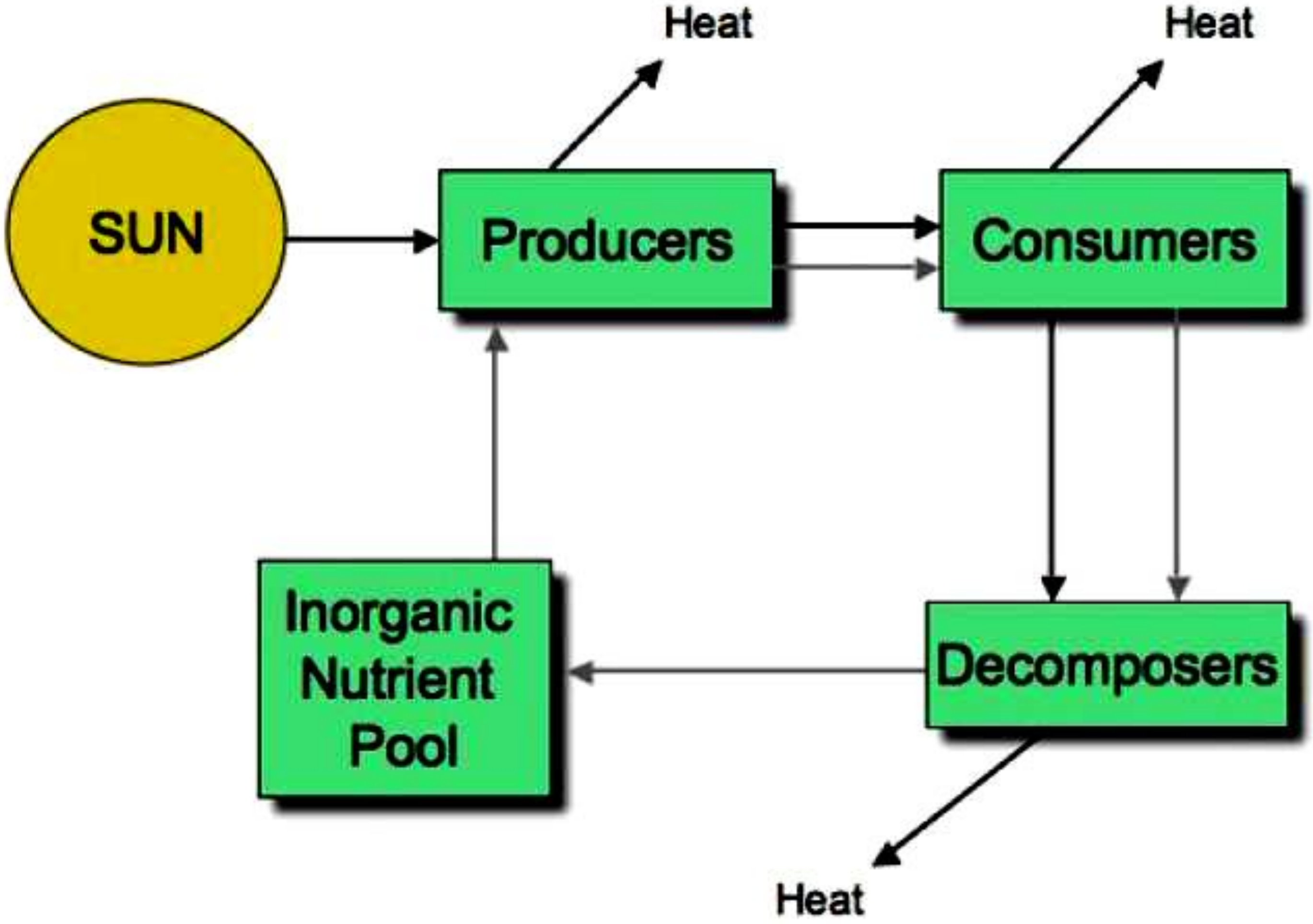
The energy flow takes place via the food chain and food web. During the process of energy flow in the ecosystem, plants being the producers absorb sunlight with the help of the chloroplasts and a part of it is transformed into chemical energy in the process of photosynthesis.

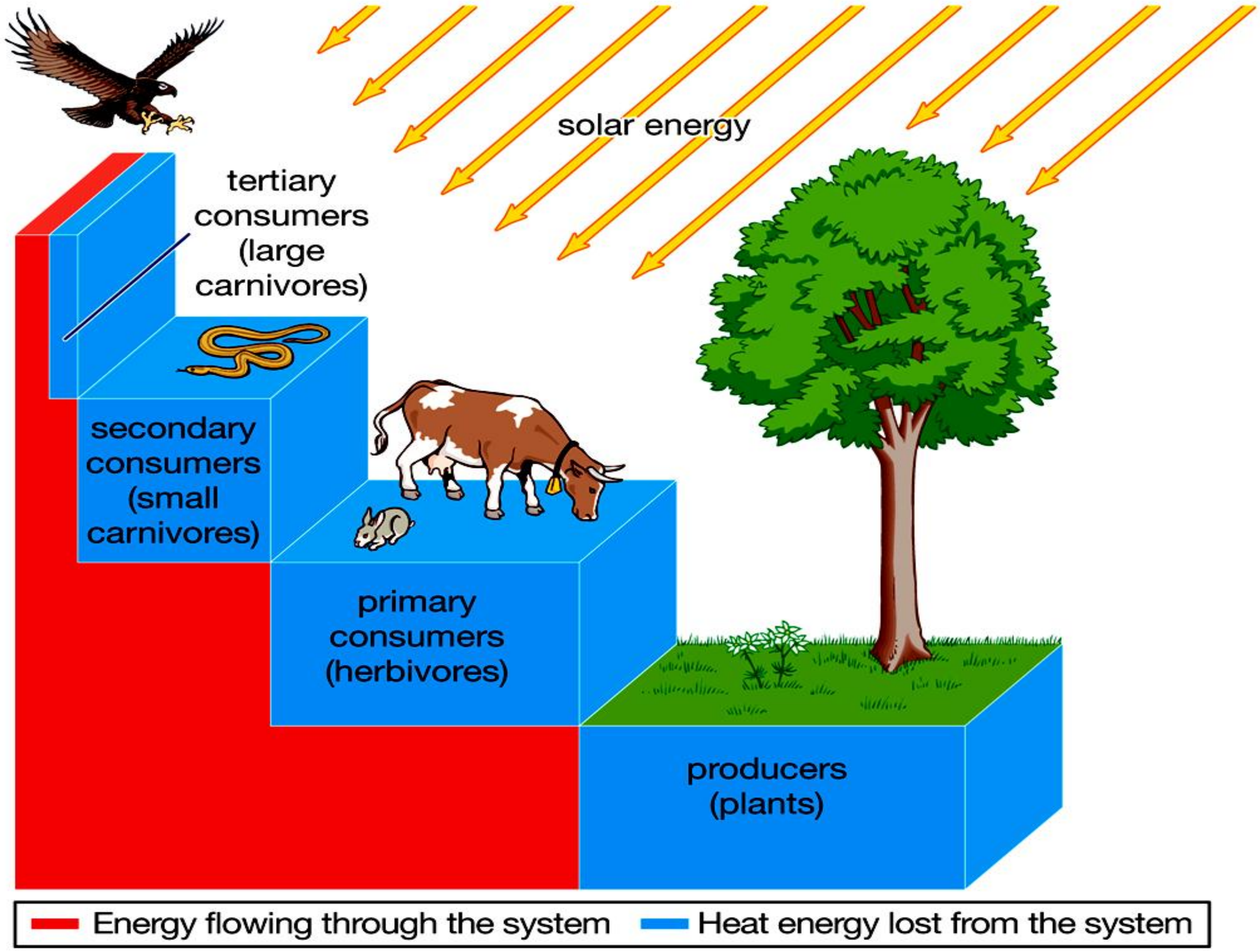
This energy is stored in various organic products in the plants and passed on to the primary consumers in the food chain when the herbivores consume (primary consumers) the plants as food. Then conversion of chemical energy stored in plant products into kinetic energy occurs, degradation of energy will occur through its conversion into heat.

Then followed by the secondary consumers. When these herbivores are ingested by carnivores of the first order (secondary consumers) further degradation will occur. Finally, when tertiary consumers consume the carnivores, energy will again be degraded. Thus, the energy flow is unidirectional in nature.

Moreover, in a food chain, the energy flow follows the 10 percent law. According to this law, only 10 percent of energy is transferred from one trophic level to the other; rest is lost into the atmosphere. The **10 percent law of energy flow** states that when the energy is passed on from one trophic level to another, only 10 percent of the energy is passed on to the next trophic level.

Energy moves life. The cycle of energy is based on the flow of energy through different trophic levels in an ecosystem. Our ecosystem is maintained by the cycling energy and nutrients obtained from different external sources. At the first trophic level, primary producers use solar energy to produce organic material through photosynthesis.


Heat
Heat
SUN
Producers
Consumers
Inorganic Nutrient Pool
Decomposers
Heat


solar energy
tertiary consumers (large carnivores)
secondary consumers (small carnivores)
primary consumers (herbivores)
producers (plants)
🟥 Energy flowing through the system
🟦 Heat energy lost from the system

The herbivores at the second trophic level, use the plants as food which gives them energy. A large part of this energy is used up for the metabolic functions of these animals such as breathing, digesting food, supporting growth of tissues, maintaining blood circulation and body temperature.

The carnivores at the next trophic level, feed on the herbivores and derive energy for their sustenance and growth. If large predators are present, they represent still higher trophic level and they feed on carnivores to get energy. Thus, the different plants and animal species are linked to one another through food chains.

Decomposers which include bacteria, fungi, molds, worms, and insects break down wastes and dead organisms, and return the nutrients to the soil, which is then taken up by the producers. Energy is not recycled during decomposition, but it is released.

Biogeochemical Cycles:

All elements in the earth are recycled time and again. The major elements such as oxygen, carbon, nitrogen, phosphorous, and sulphur are essential ingredients that make up organisms.

Biogeochemical cycles refer to the flow of such chemical elements and compounds between organisms and the physical environment. Chemicals taken in by organisms are passed through the food chain and come back to the soil, air, and water through mechanisms such as respiration, excretion, and decomposition.

As an element moves through this cycle, it often forms compounds with other elements as a result of metabolic processes in living tissues and of natural reactions in the atmosphere, hydrosphere, or lithosphere.

Such cyclic exchange of material between the living organisms and their non-living environment is called Biogeochemical Cycle.

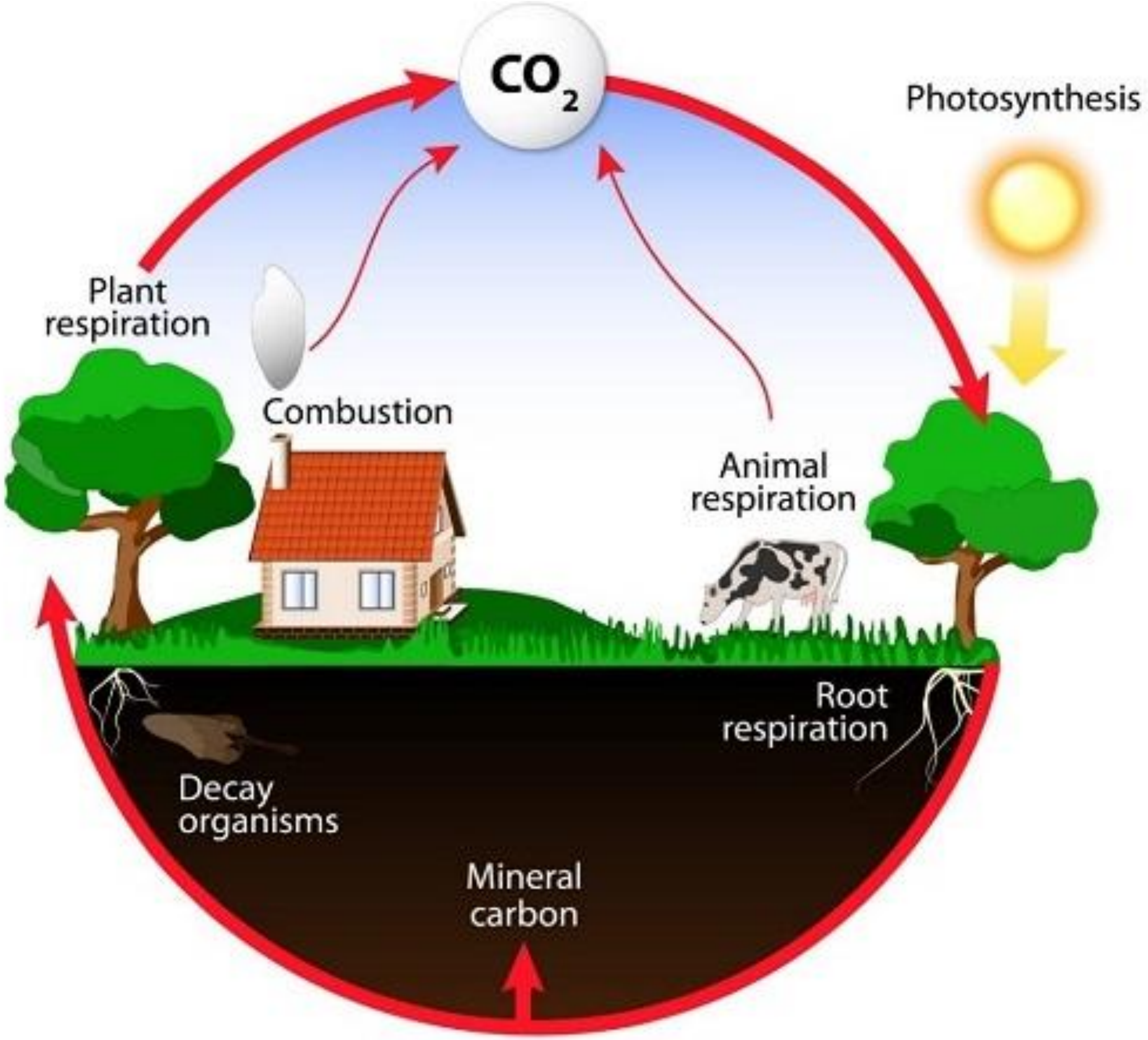
Following are some important biogeochemical cycles –

- Carbon Cycle
- Nitrogen Cycle
- Water Cycle
- Oxygen Cycle
- Phosphorus Cycle

- Sulphur Cycle

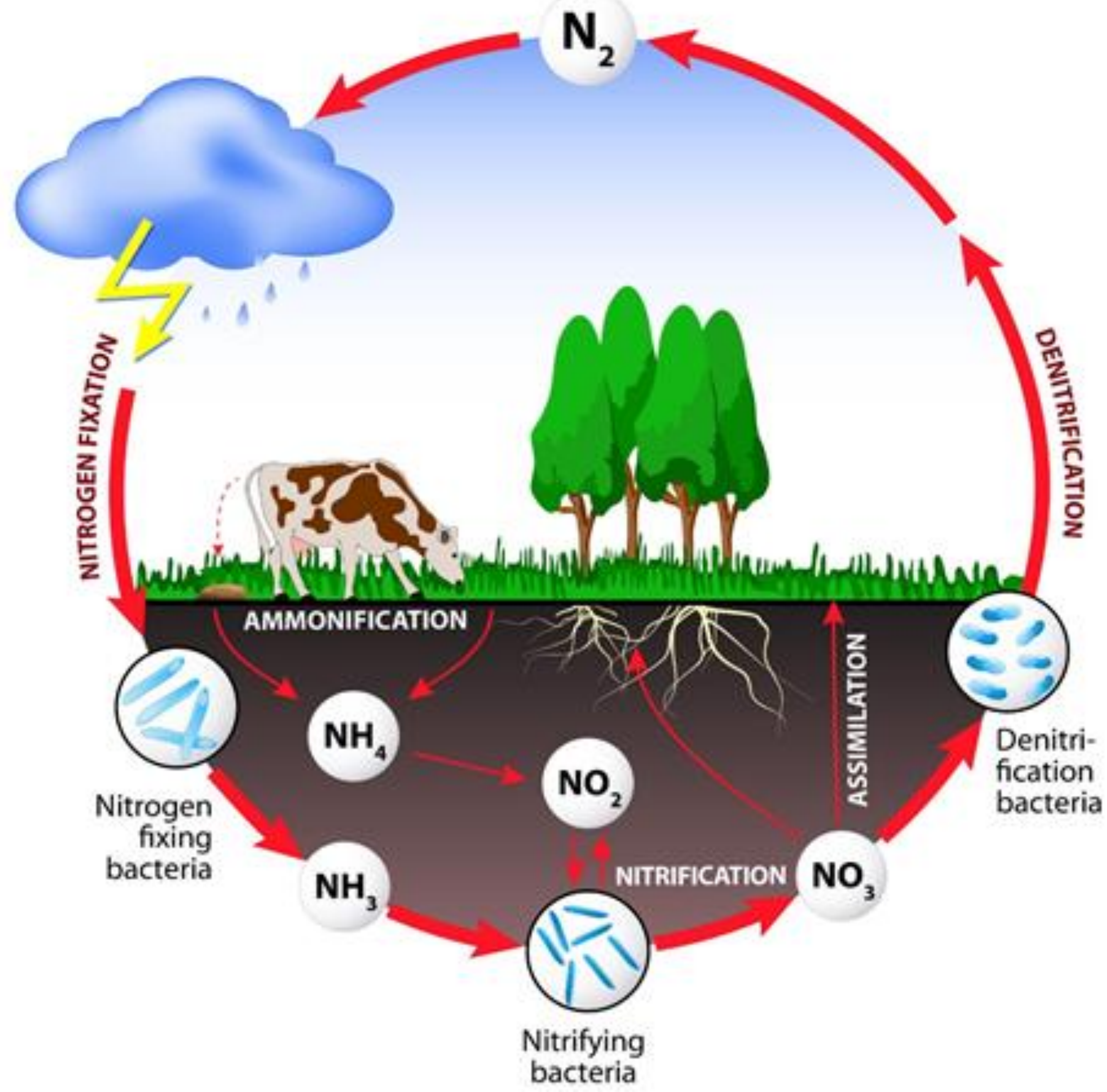
Carbon Cycle:

Carbon enters into the living world in the form of carbon dioxide through the process of photosynthesis as carbohydrates. These organic compounds (food) are then passed from the producers to the consumers (herbivores & carnivores). This carbon is finally returned to the surrounding medium by the process of respiration or decomposition of plants and animals by the decomposers. Carbon is also recycled during the burning of fossil fuels.


CO_2
Photosynthesis
Plant respiration
Combustion
Animal respiration
Root respiration
Decay organisms
Mineral carbon

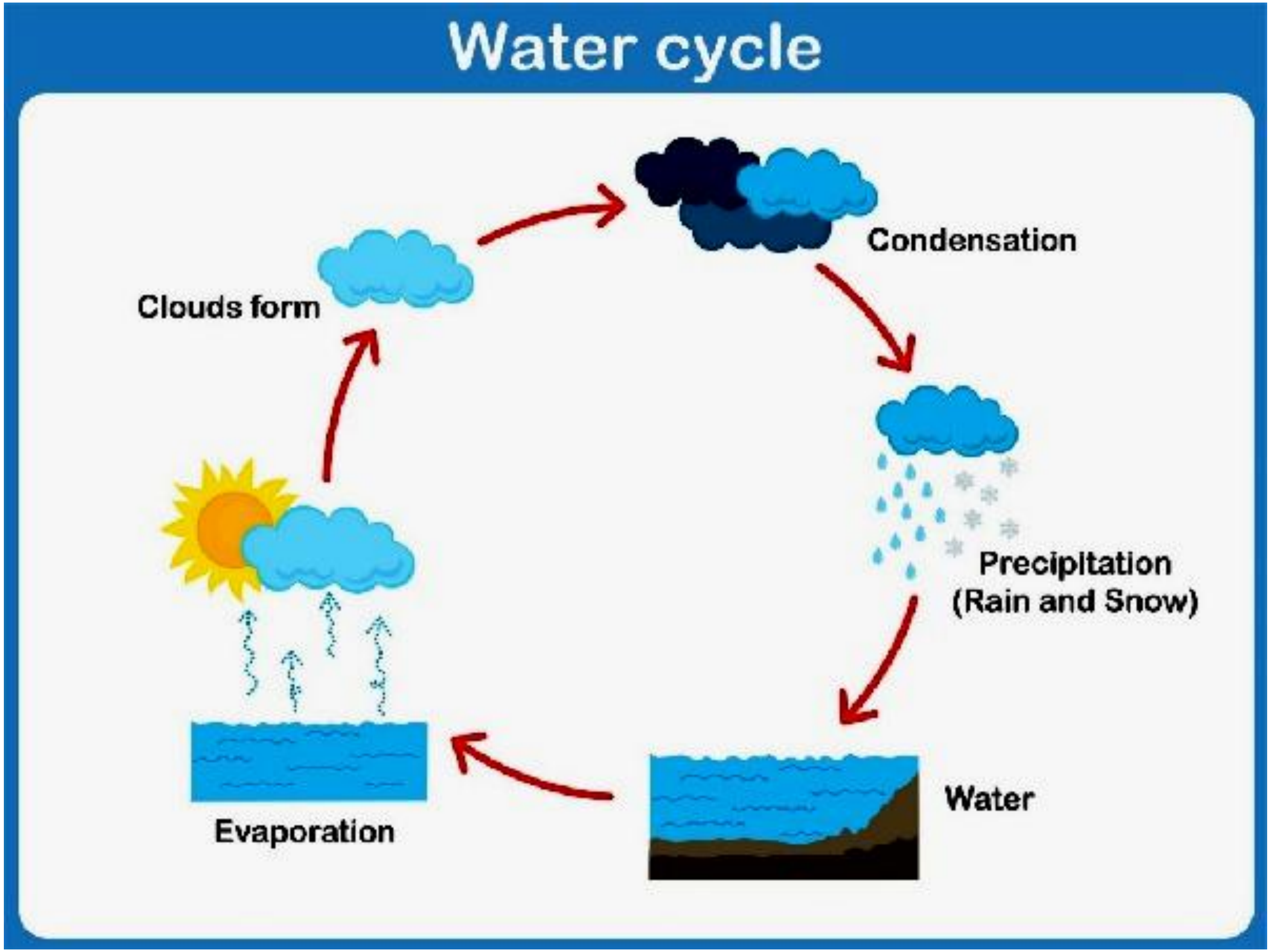
Nitrogen Cycle:

Nitrogen is present in the atmosphere in an elemental form and as such it cannot be utilized by living organisms. This elemental form of nitrogen is converted into combined state with elements such as H, C, O by certain bacteria, so that it can be readily used by the plants. Nitrogen is being continuously expelled into the air by the action of microorganisms such as denitrifying bacteria and finally returned to the cycle through the action of lightening and electrification.


N_2
NITROGEN FIXATION
DENITRIFICATION
AMMONIFICATION
NH_4
NO_2
ASSIMILATION
Denitri-fication bacteria
Nitrogen fixing bacteria
NH_3
NITRIFICATION
NO_3
Nitrifying bacteria

Water Cycle:

The evaporation of water from ocean, rivers, lakes, and transpiring plants takes water in the form of vapors to the atmosphere. This vaporized water subsequently cools and condenses to form cloud and water. This cooled water vapor ultimately returns to the earth as rain and snow, completing the cycle.


Water cycle
Condensation
Clouds form
Precipitation
(Rain and Snow)
Water
Evaporation

How Organisms Acquire Energy in a Food Web?

All living things require energy in one form or another since energy is required by most, complex, metabolic pathways (often in the form of ATP); life itself is an energy-driven process. Living organisms would not be able to assemble macromolecules (proteins, lipids, nucleic acids, and complex carbohydrates) from their monomeric subunits without a constant energy input.

It is important to understand how organisms acquire energy and how that energy is passed from one organism to another through food webs and their constituent food chains. Food webs illustrate how energy flows directionally through ecosystems, including how efficiently organisms acquire it, use it, and how much remains for use by other organisms of the food web. Energy is acquired by living things in three ways: photosynthesis, chemosynthesis, and the consumption and digestion of other living or previously-living organisms by heterotrophs.

Photosynthetic and chemosynthetic organisms are grouped into a category known as autotrophs: organisms capable of synthesizing their own food (more specifically, capable of using inorganic carbon as a carbon source). Photosynthetic autotrophs (photoautotrophs) use sunlight as an energy source, whereas chemosynthetic autotrophs (chemoautotrophs) use inorganic molecules as an energy source. Autotrophs act as producers and are critical for all ecosystems. Without these organisms, energy would not be available to other living organisms and life itself would not be possible.

Photoautotrophs, such as plants, algae, and photosynthetic bacteria, serve as the energy source for a majority of the world's ecosystems. These ecosystems are often described by grazing food webs. Photoautotrophs harness the solar energy of the sun by converting it to chemical energy in the form of ATP (and NADP). The energy stored in ATP is used to synthesize complex organic molecules, such as glucose.

Chemoautotrophs are primarily bacteria that are found in rare ecosystems where sunlight is not available, such as in those associated with dark caves or hydrothermal vents at the bottom of the ocean. Many chemoautotrophs in hydrothermal vents use hydrogen sulfide (H_2S), which is released from the vents, as a source of chemical energy. This allows chemoautotrophs to synthesize complex organic molecules, such as glucose, for their own energy and in turn supplies energy to the rest of the ecosystem.

Chemoautotrophs: Swimming shrimp, a few squat lobsters, and hundreds of vent mussels are seen at a hydrothermal vent at the bottom of the ocean. As no sunlight penetrates to this depth, the ecosystem is supported by chemoautotrophic bacteria and organic material that sinks from the ocean’s surface.

Heterotrophs function as consumers in the food chain; they obtain energy in the form of organic carbon by eating autotrophs or other heterotrophs. They break down complex organic compounds produced by autotrophs into simpler compounds, releasing energy by oxidizing carbon and hydrogen atoms into carbon dioxide and water, respectively. Unlike autotrophs, heterotrophs are unable to synthesize their own food. If they cannot eat other organisms, they will die.

Productivity within Trophic Levels:

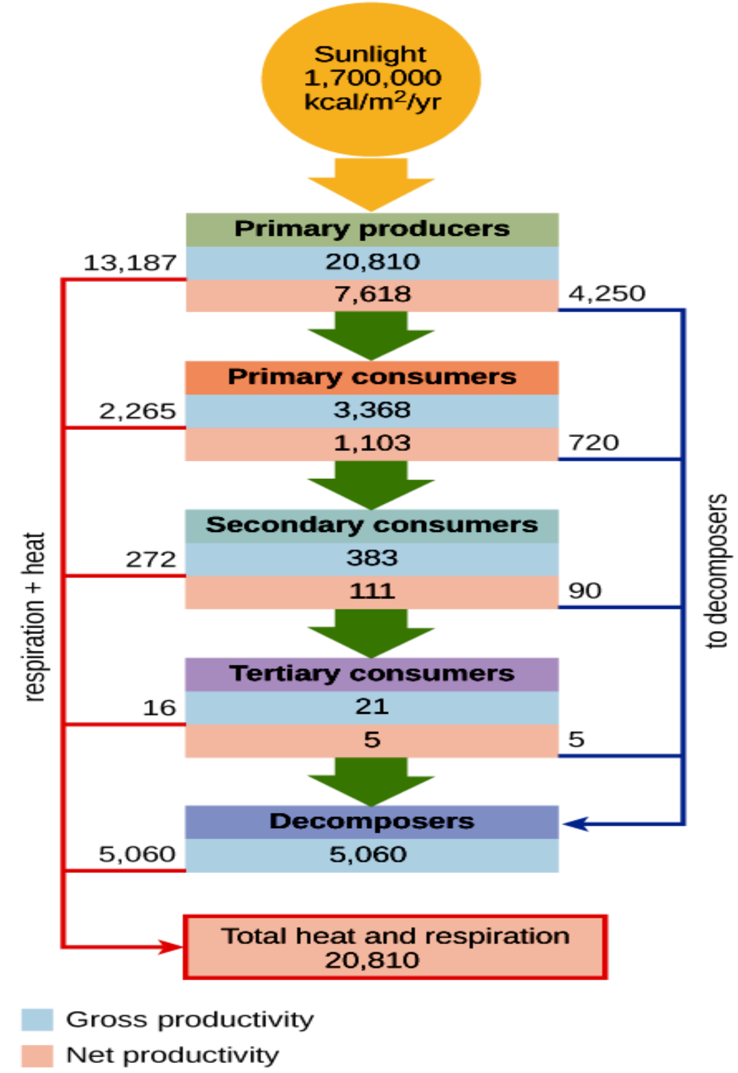
Productivity, measured by gross and net primary productivity, is defined as the amount of energy that is incorporated into a biomass. In ecology, productivity is the rate at which energy is added to the bodies of organisms in the form of biomass. Biomass is simply the amount of matter that's stored in the bodies of a group of organisms. Productivity can be defined for any trophic level or other group, and it may take units of either energy or biomass. There are two basic types of productivity: gross and net.

- **Gross primary productivity, or GPP**, is the rate at which solar energy is captured in sugar molecules during photosynthesis—energy captured per unit area per unit time. Producers such as plants use some of this energy for metabolism/cellular respiration and some for growth, building tissues.

- **Net primary productivity, or NPP,** is gross primary productivity minus the rate of energy loss to metabolism and maintenance. In other words, it's the rate at which energy is stored as biomass by plants or other primary producers and made available to the consumers in the ecosystem.

Productivity within an ecosystem can be defined as the percentage of energy entering the ecosystem incorporated into biomass in a particular trophic level. Biomass is the total mass in a unit area (at the time of measurement) of living or previously-living organisms within a trophic level. Ecosystems have characteristic amounts of biomass at each trophic level. For example, in the English Channel ecosystem, the primary producers account for a biomass of 4 g/m^2 (grams per meter squared), while the primary consumers exhibit a biomass of 21 g/m^2.

The productivity of the primary producers is especially important in any ecosystem because these organisms bring energy to other living organisms by photoautotrophy or chemoautotrophy. Photoautotrophy is the process by which an organism (such as a green plant) synthesizes its own food from inorganic material using light as a source of energy; chemoautotrophy, on the other hand, is the process by which simple organisms (such as bacteria or archaea) derive energy from chemical processes rather than photosynthesis. The rate at which photosynthetic primary producers incorporate energy from the sun is called gross primary productivity. An example of gross primary productivity is the compartment diagram of energy flow within the Silver Springs aquatic ecosystem. In this ecosystem, the total energy accumulated by the primary producers was shown to be 20,810 kcal/m^2/yr.


Sunlight
1,700,000
kcal/m2/yr
Primary producers
20,810
7,618
13,187
4,250
Primary consumers
3,368
1,103
2,265
720
Secondary consumers
383
111
272
90
Tertiary consumers
21
5
16
5
Decomposers
5,060
5,060
respiration + heat
to decomposers
Total heat and respiration
20,810
Gross productivity
Net productivity

Because all organisms need to use some of this energy for their own functions (such as respiration and resulting metabolic heat loss), scientists often refer to the net primary productivity of an ecosystem. Net primary productivity is the energy that remains in the primary producers after accounting for the organisms' respiration and heat loss. The net productivity is then available to the primary consumers at the next trophic level. In the Silver Spring example, 13,187 of the 20,810 kcal/m^2/yr were used for respiration or were lost as heat, leaving 7,632 kcal/m^2/yr of energy for use by the primary consumers.

Transfer of Energy between Trophic Levels:

Energy is lost as it is transferred between trophic levels; the efficiency of this energy transfer is measured by NPE and TLTE. Energy decreases as it moves up trophic levels because energy is lost as metabolic heat when the organisms from one trophic level are consumed by organisms from the next level.

- Trophic level transfer efficiency (TLTE) measures the amount of energy that is transferred between trophic levels.

- A food chain can usually sustain no more than six energy transfers before all the energy is used up.
- Net production efficiency (NPE) measures how efficiently each trophic level uses and incorporates the energy from its food into biomass to fuel the next trophic level.
- Endotherms have a low NPE and use more energy for heat and respiration than ectotherms, so most endotherms have to eat more often than ectotherms to get the energy they need for survival.

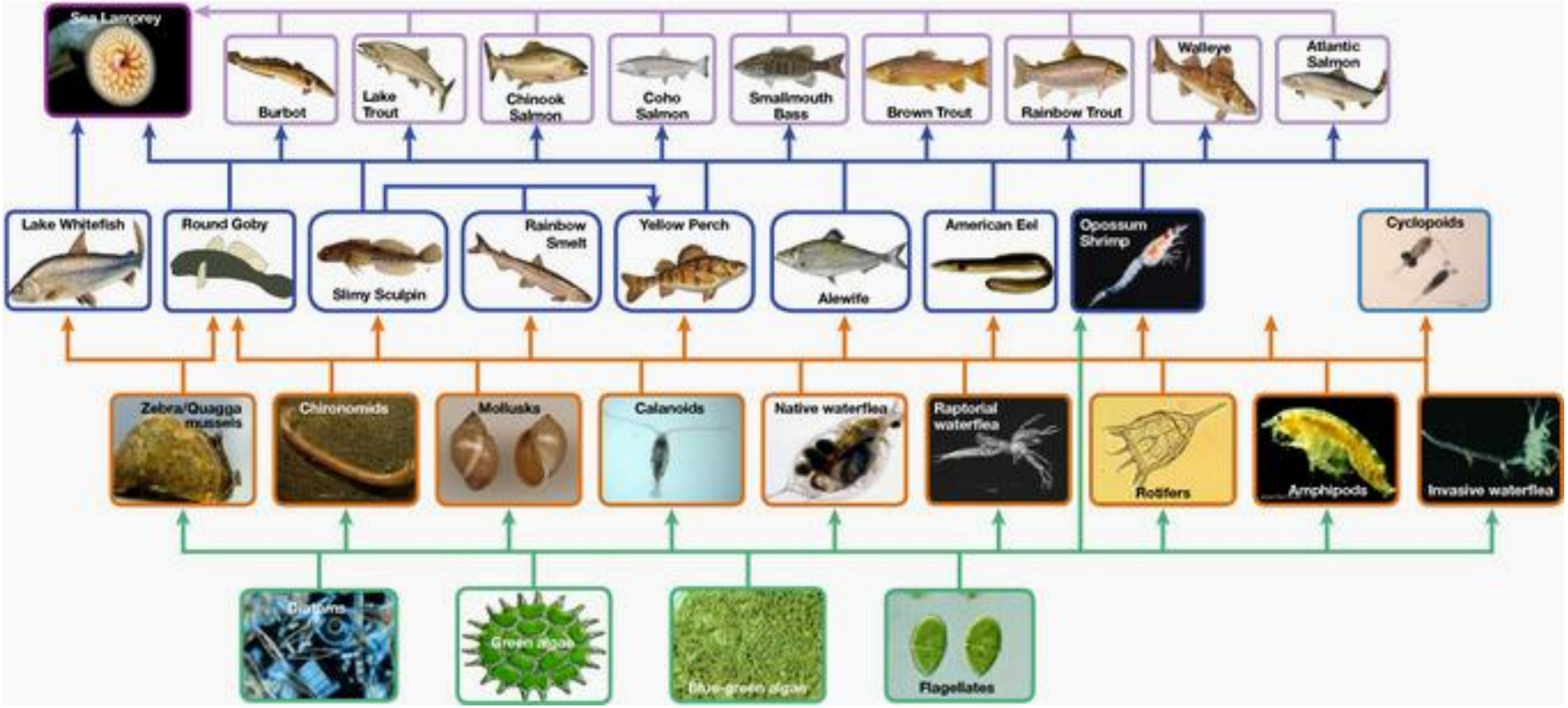
- Since cattle and other livestock have low NPEs, it is more costly to produce energy content in the form of meat and other animal products than in the form of corn, soybeans, and other crops.
-

Ecological efficiency: the transfer of energy between trophic levels:

Large amounts of energy are lost from the ecosystem between one trophic level and the next level as energy flows from the primary producers through the various trophic levels of consumers and decomposers. The main reason for this loss is the second law of thermodynamics, which states that whenever energy is converted from one form to another, there is a tendency toward disorder (entropy) in the system. In biologic systems, this means a great deal of energy is lost as metabolic heat when the organisms from one trophic level are consumed by the next level. The measurement of energy transfer efficiency between two successive trophic levels is termed the trophic level transfer efficiency (TLTE) and is defined by the formula:

$$\text{TLTE} = \frac{\text{production at present trophic level}}{\text{production at previous trophic level}} \text{x}100$$

In Silver Springs, the TLTE between the first two trophic levels was approximately 14.8 percent. The low efficiency of energy transfer between trophic levels is usually the major factor that limits the length of food chains observed in a food web. The fact is, after four to six energy transfers, there is not enough energy left to support another trophic level. In the Lake Ontario ecosystem food web, only three energy transfers occurred between the primary producer (green algae) and the tertiary, or apex, consumer (Chinook salmon).



Ecologists have many different methods of measuring energy transfers within ecosystems. Some transfers are easier or more difficult to measure depending on the complexity of the ecosystem and how much access scientists have to observe the ecosystem. In other words, some ecosystems are more difficult to study than others; sometimes the quantification of energy transfers has to be estimated.

Net production efficiency:

Another main parameter that is important in characterizing energy flow within an ecosystem is the net production efficiency. Net production efficiency (NPE) allows ecologists to quantify how efficiently organisms of a particular trophic level incorporate the energy they receive into biomass. It is calculated using the following formula:

$$\mathrm{NPE} = \frac{\text{net consumer productivity}}{\text{assimilation}} \mathrm{x}100$$

Net consumer productivity is the energy content available to the organisms of the next trophic level. Assimilation is the biomass (energy content generated per unit area) of the present trophic level after accounting for the energy lost due to incomplete ingestion of food, energy used for respiration, and energy lost as waste. Incomplete ingestion refers to the fact that some consumers eat only a part of their food. For example, when a lion kills an antelope, it will eat everything except the hide and bones. The lion is missing the energy-rich bone marrow inside the bone, so the lion does not make use of all the calories its prey could provide.

Thus, NPE measures how efficiently each trophic level uses and incorporates the energy from its food into biomass to fuel the next trophic level. In general, cold-blooded animals (ectotherms), such as invertebrates, fish, amphibians, and reptiles, use less of the energy they obtain for respiration and heat than warm-blooded animals (endotherms), such as birds and mammals. The extra heat generated in endotherms, although an advantage in terms of the activity of these organisms in colder environments, is a major disadvantage in terms of NPE. Therefore, many endotherms have to eat more often than ectotherms to obtain the energy they need for survival. In general, NPE for ectotherms is an order of magnitude (10x) higher than for endotherms. For example, the NPE for a caterpillar eating leaves has been measured at 18 percent, whereas the NPE for a squirrel eating acorns may be as low as 1.6 percent.

The inefficiency of energy use by warm-blooded animals has broad implications for the world’s food supply. It is widely accepted that the meat industry uses large amounts of crops to feed livestock. Because the NPE is low, much of the energy from animal feed is lost. For example, it costs about $0.01 to produce 1000 dietary calories (kcal) of corn or soybeans, but approximately $0.19 to produce a similar number of calories growing cattle for beef consumption. The same energy content of milk from cattle is also costly, at approximately $0.16 per 1000 kcal. Much of this difference is due to the low NPE of cattle. Thus, there has been a growing movement worldwide to promote the consumption of non-meat and non-dairy foods so that less energy is wasted feeding animals for the meat industry.

THANK YOU