GATE ECOLOGY AND EVOLUTION

QUICK ACHIEVER COURSE

Dr. SAGAR ADHURYA

Postdoctoral Researcher, Kyunghee University, South Korea

GATE (Ecology and Evolution) 2016: AIR 08

Email: sagaradhurya@gmail.com

WhatsApp: +91 9474739327

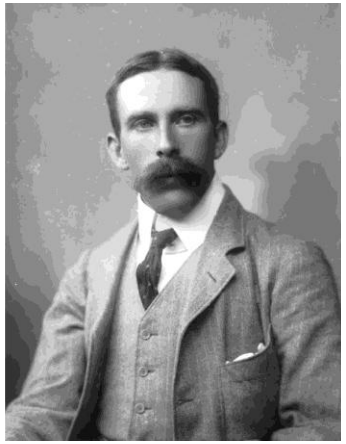
ECOSYSTEMS STRUCTURE AND FUNCTION

Ecosystem

- **Ecosystem** is a unit that includes all the organisms that functions together (the biotic community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined biotic structures and cycling of materials between living and non-living parts.
- The term was coined by Sir Arthur George Tansley in 1935.
- Another equivalent term for the ecosystem as coined by

Karl Mobius was **biocoenose**.

- Ecosystem = biotic + abiotic



Arthur George Tansley (1871-1955)

Trophic level

- *Trophe* = nourishment
- The position of a species or a group of species within a food chain or food web.
- The concept of trophic level was developed by Raymond Lindeman (1942)
- **Autotrophs:** Photosynthetic and chemosynthetic organisms
- **Heterotrophs:** Depends on another organisms to fulfill their energy and nutrient requirement. Ex. Fungi, animals etc.
    - **Macroconsumers:** These are chiefly animals those consumes other organisms or particulate organic matter.
    - **Microconsumers:** These are mainly bacteria, protozoa and fungi. That obtain their food either by breakdown of dead tissues or by absorbing dissolved organic matter extruded by or extracted from other organisms.
- **Some other used terms:**
    - **Phagotrophs *(phago,* to eat)*:*** Obtains nutrient through the ingestion of solid organic matter.
    - **Osmotroph (*osmo*, to pass through a membrane):** obtain their nutrient by absorbing dissolved organic matter.
    - **Saprotroph (*sapro*, to decompose):** A heterotrophs that obtains their food from non-living organic matters.

Some important terminologies

- **Standing crop:** Total number (biomass) of living organisms present in different trophic levels.
- **Turnover rate:** It is the ratio of the standing state of the biotic or abiotic compartment to the rate of replacement of the standing state.
    - Suppose biomass of a forest is 20000 g/m^2, the annual growth increment is 1000 g. Then the ratio 20000/1000 is the *turnover time* ***or*** *replacement time.* The reciprocal (1/20) is called *turnover rate*.
- **Detritus:** Decaying organic matter. Animals that feeds on detritus called *detritivore*.
- **Humus:** Humus are end product of decomposition, that are quite resistant for further decay and never found inside cells.

Energy flow

- **Energy** is defined as the ability to do work.
- The behaviour of energy follows the rules of thermodynamics:
  - **First law** or **the law of conservation of energy** states that energy can neither be created nor be destroyed, it can only be converted from one form to another.
  - **Second law** or **the law of entropy** states that:
    - no process involving an energy transformation will spontaneously occur unless there is a degradation of energy from a concentrated form to a dispersed form.
    - As some energy is always dispersed into unavailable heat energy, no spontaneous transformation of energy into potential energy is 100 percent efficient.
- **Entropy** is a measure of unavailable energy resulting from transformations.

Solar radiation

- **Solar flux:** About one fifty-millionth of the sun's energy output reaches the outer atmosphere of the earth in a constant rate, called solar flux.
- About 48% of solar flux reaches the earth's outer surface.
- The extra-terrestrial sunlight reaches the ionosphere at a constant rate of 2 gcal/cm^2/min, it is referred as **solar constant**.
- Only a small fraction of visible light can be converted to organic matter: 5%.

Productivity

- The rate of production of energy/biomass is called **productivity.**
- It is usually measured in terms of energy (J m^{-2} d^{-1}) or dry mass (kg ha^{-1} $year^{-1}$).
- The rate at which radiant solar energy is converted to organic substances by the autotrophs is called **primary productivity.**
    - Total fixation of energy by photosynthesis is called **gross primary productivity (GPP).**
    - Some proportion of the GPP is lost to due to respiratory activities of the plant, is called **respiratory loss (R).**
    - The portion of GPP which remained in the plant tissues after respiratory loss is called **net primary production (NPP).** $NPP = GPP - R$
    - Terrestrial plants are rooted in soil which contains many organisms those mainly function as decomposers. The energy utilised by these soil organisms is unavailable for the consumers of the plant. Because of the intimate relationship between soil organisms and plant, ecologists often considers the two as a unit. **Net ecosystem production (NEP)** is the difference between GPP and energetic costs of both plants and soil organisms.
    $$NEP = GPP - Respiratory\ losses\ by\ plants - Respiratory\ losses\ of\ soil\ organisms$$
- The rate of production of biomass by heterotrophs is called **secondary productivity.**
- The rate of storage of organic matter in the ecosystem after consumption by the heterotrophs, is called **net community productivity (NCP)**. $NCP = NPP - heterotrophic\ grazing$

Method to estimate NPP

TABLE 10-1 Common methods used to measure primary production

Method	Description	Habitat
Calorimetry	Sample of plant tissue is burned in bomb calorimeter. Energy content of organic compounds is calculated from heat energy released during burning.	Terrestrial
Harvesting	Samples of plant tissue are obtained, dried, and weighed. Dry weight of plant biomass is used as measure of production.	Terrestrial; large aquatic plants
CO_2 flux	CO_2 uptake of plant or plant part is measured in a closed container.	Terrestrial and aquatic
O_2 flux	Production of O_2 by plants or algae is measured in a closed container.	Usually aquatic
Chlorophyll concentration	Chlorophyll is extracted and its concentration measured. Concentration is compared with the rate of assimilation of carbon per gram of chlorophyll for the particular plant or alga under study.	Usually aquatic

Method to estimate NPP

- In terrestrial ecosystem the NPP is measured from standing crop biomass (SCB): $\Delta SCB = SCB(t_1) - SCB(t_2)$. Two possible reason for the loss of plant biomass is death (D) and loss of biomass by consumption by consumers (C). $NPP = \Delta SCB + D + C$.
- In aquatic ecosystem the most common method to estimate NPP is light/dark bottle method:
    1. Take water collected from natural source in one light and one dark bottle.
    2. Measure the initial O_2 concentrations in both bottle and seal it.
    3. Place the light bottle at sunlight to allow photosynthesis, while in dark bottle there are no photosynthesis.
    4. Measure O_2 after 1 hrs.

Suppose:

- Initial O_2 concentration = 8 mg/l
- O_2 conc in light bottle after a hour = 10 mg/l
- O_2 conc in dark bottle after a hour = 5 mg/l
- Light-Initial = GPP-R = NPP = 10-8 = 2 mg/l
- Initial-dark = Respiration = 8-5 = 3 mg/l
- Light-Dark = NPP+R = GPP = 10-5 = 5 mg/l

Patterns of productivity

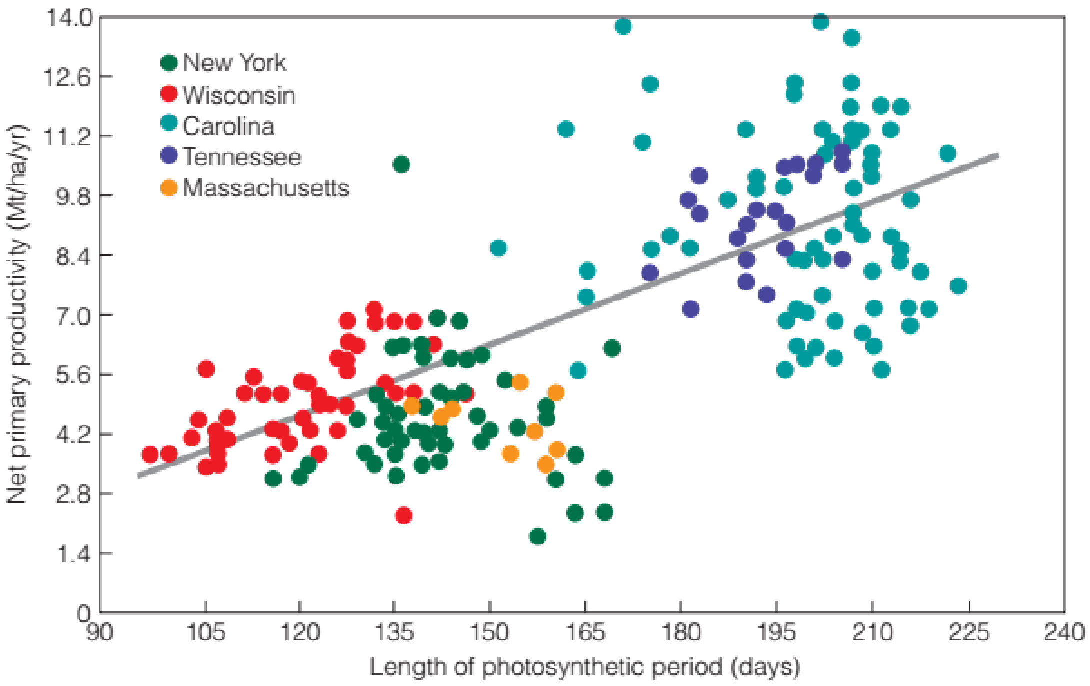
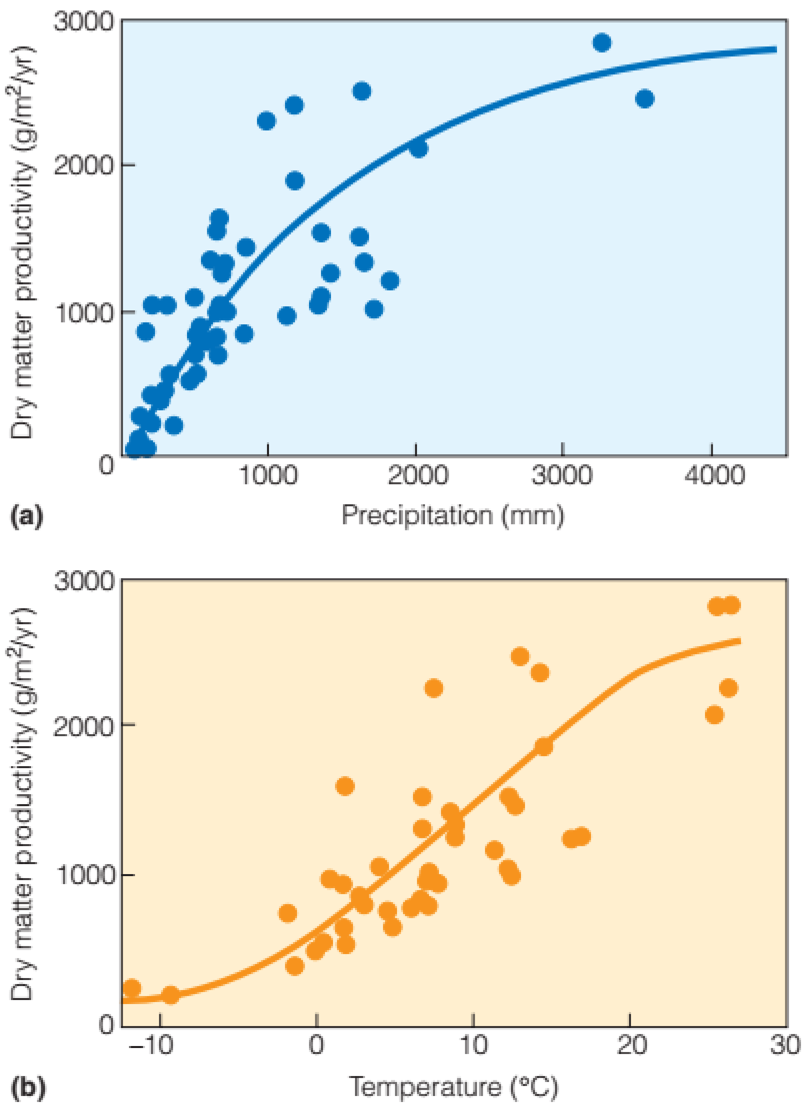


Figure 21.3 Relationship between net primary productivity and the length of the growing season for deciduous forest stands in eastern North America. Each point represents a single forest site. The (regression) line represents the general trend of increasing productivity with increasing length of the growing season (largely a function of latitude).

(Adapted from Leith 1975.)



Patterns of productivity

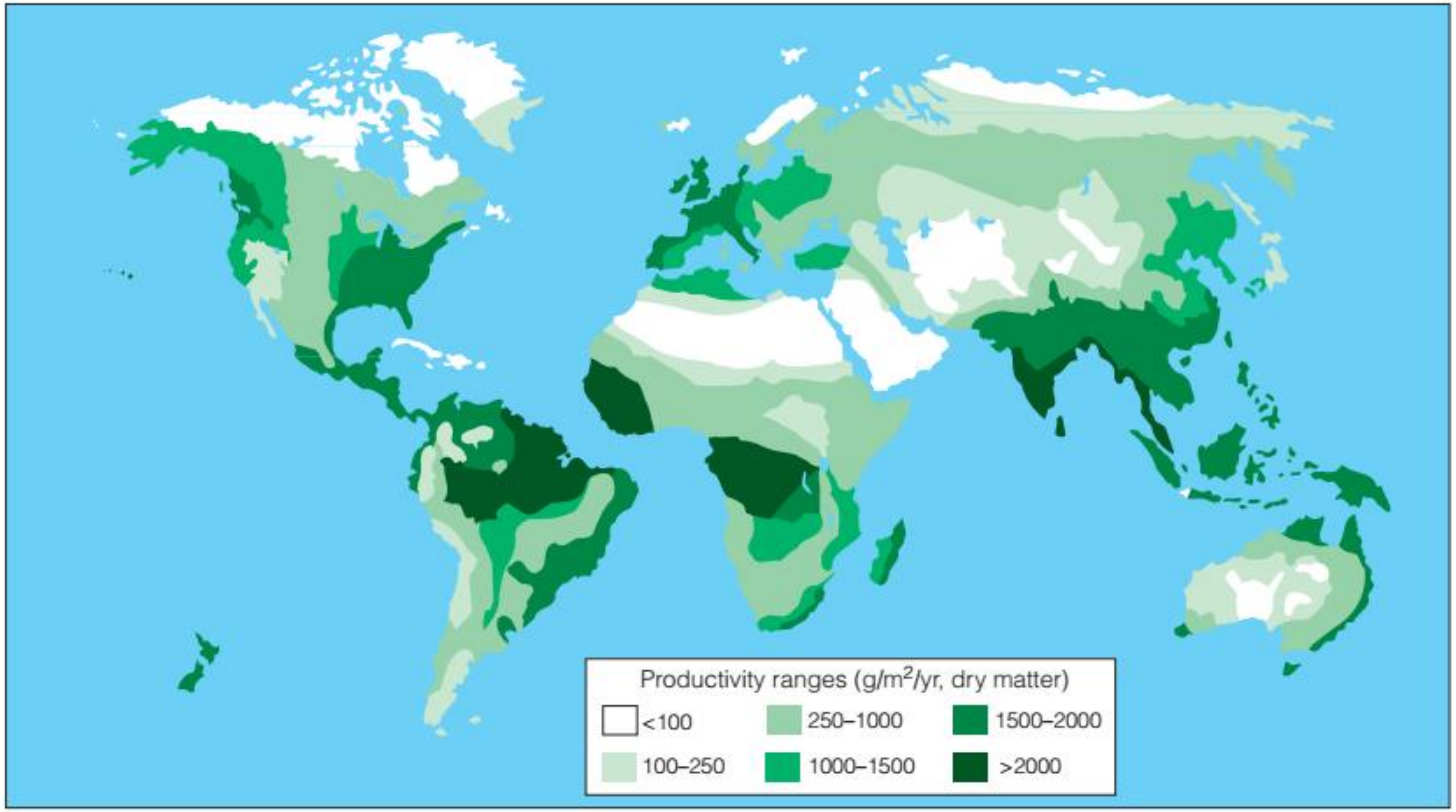


Figure 21.5 A global map of primary productivity for the terrestrial surface (ecosystems).
(Adapted from Golley and Leigh 1972.)

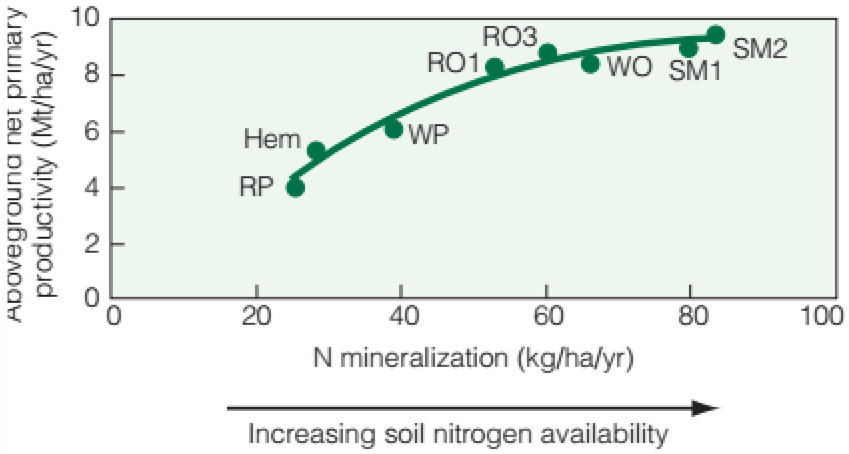


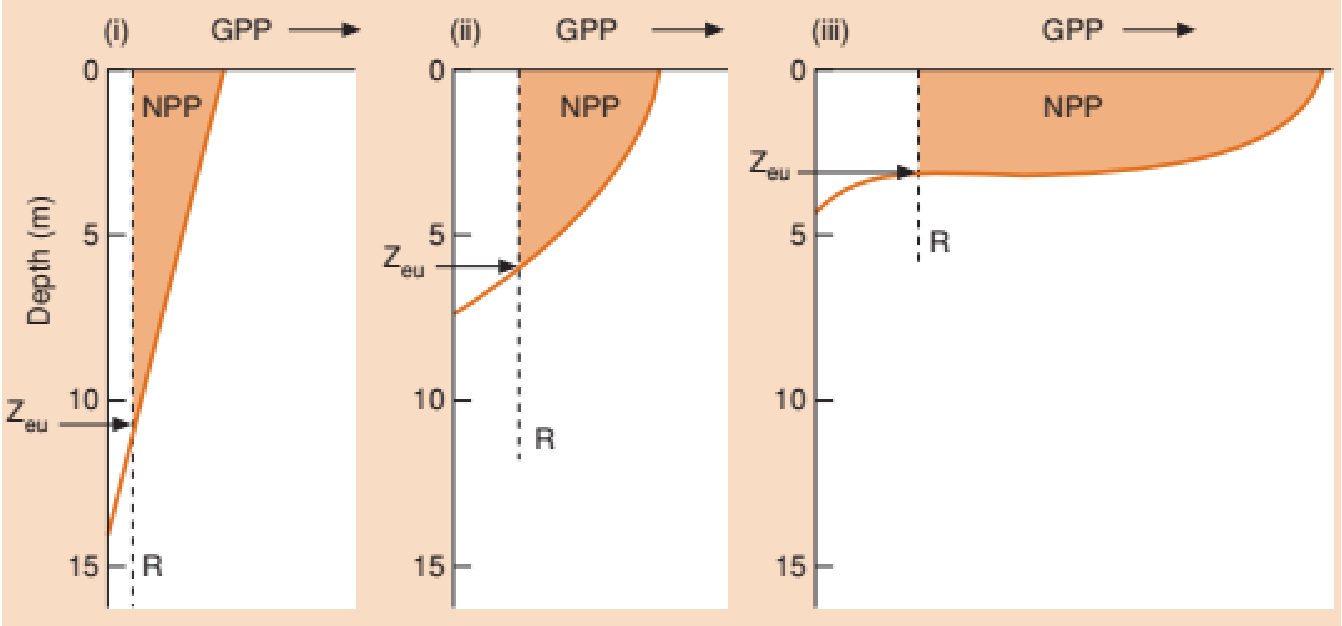
Figure 21.6 Relationship between net primary production and nutrient availability. Aboveground productivity increases with increasing nitrogen availability (N mineralization rate) for a variety of forest ecosystems on Blackhawk Island, Wisconsin. Abbreviations refer to the dominant trees in each stand: Hem, hemlock; RP, red pine; RO, red oak; WO, white oak; SM, sugar maple; WP, white pine.
(Adapted from Pastor et al. 1984.)

Patterns of productivity

Ecosystem	Net primary production ($g\ m^{-2}\ yr^{-1}$)
Terrestrial	
Tropical forest	1,800
Temperate forest	1,250
Boreal forest	800
Shrubland	600
Savanna	700
Temperate grassland	500
Tundra and alpine	140
Desert scrub	70
Cultivated land	650
Swamp and marsh	2,500

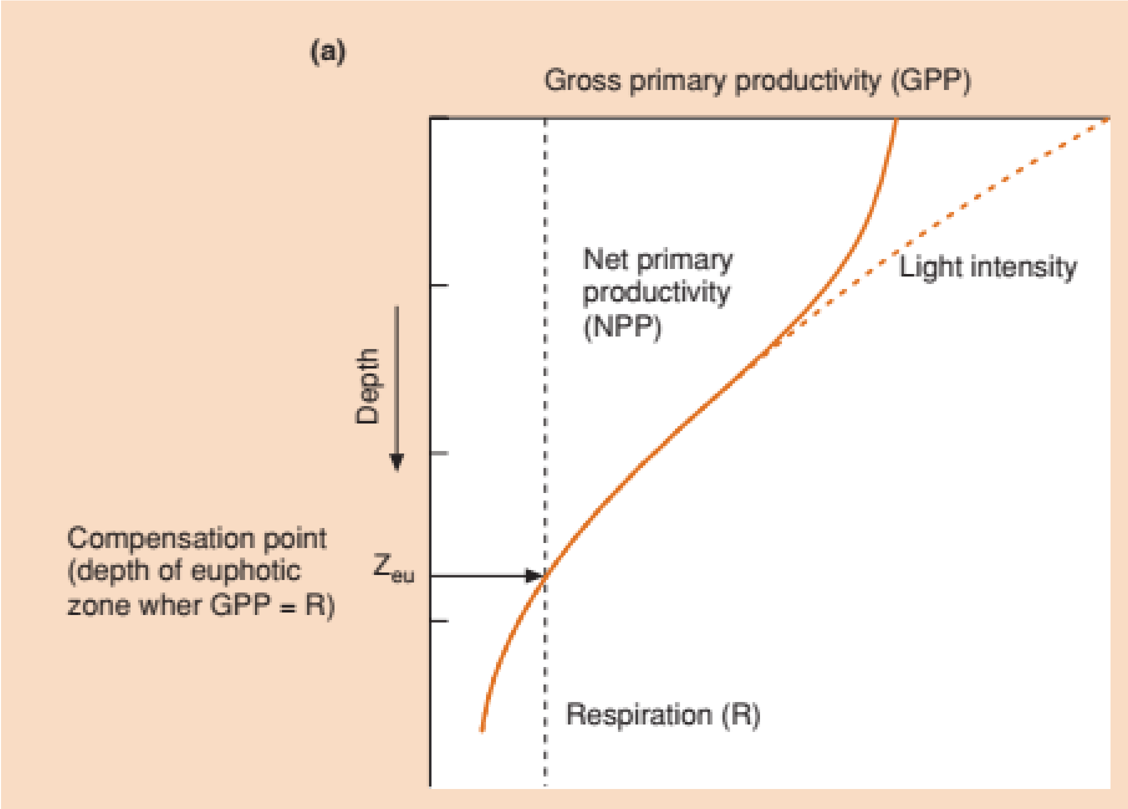
Ecosystem	Net primary production ($g\ m^{-2}\ yr^{-1}$)
Aquatic	
Open ocean	125
Continental shelf	360
Algal beds and reefs	2,000
Estuaries	1,800
Lakes and streams	500

Primary productivity in lake



Less nutrient

More nutrient



Where, GPP=R, or NPP=0, it is called **compensation point**

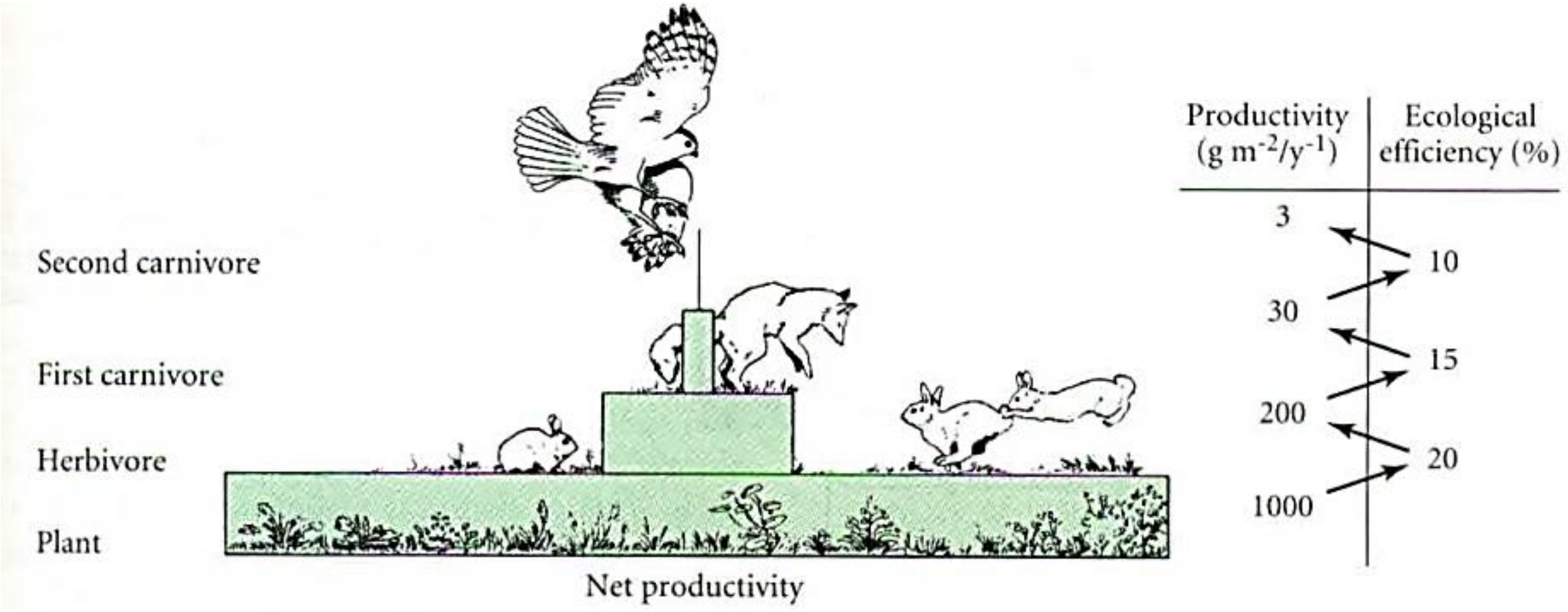
The light intensity at which the photosynthetic rate is maximum called **saturation point**

Energy subsidy and source-sink energetics

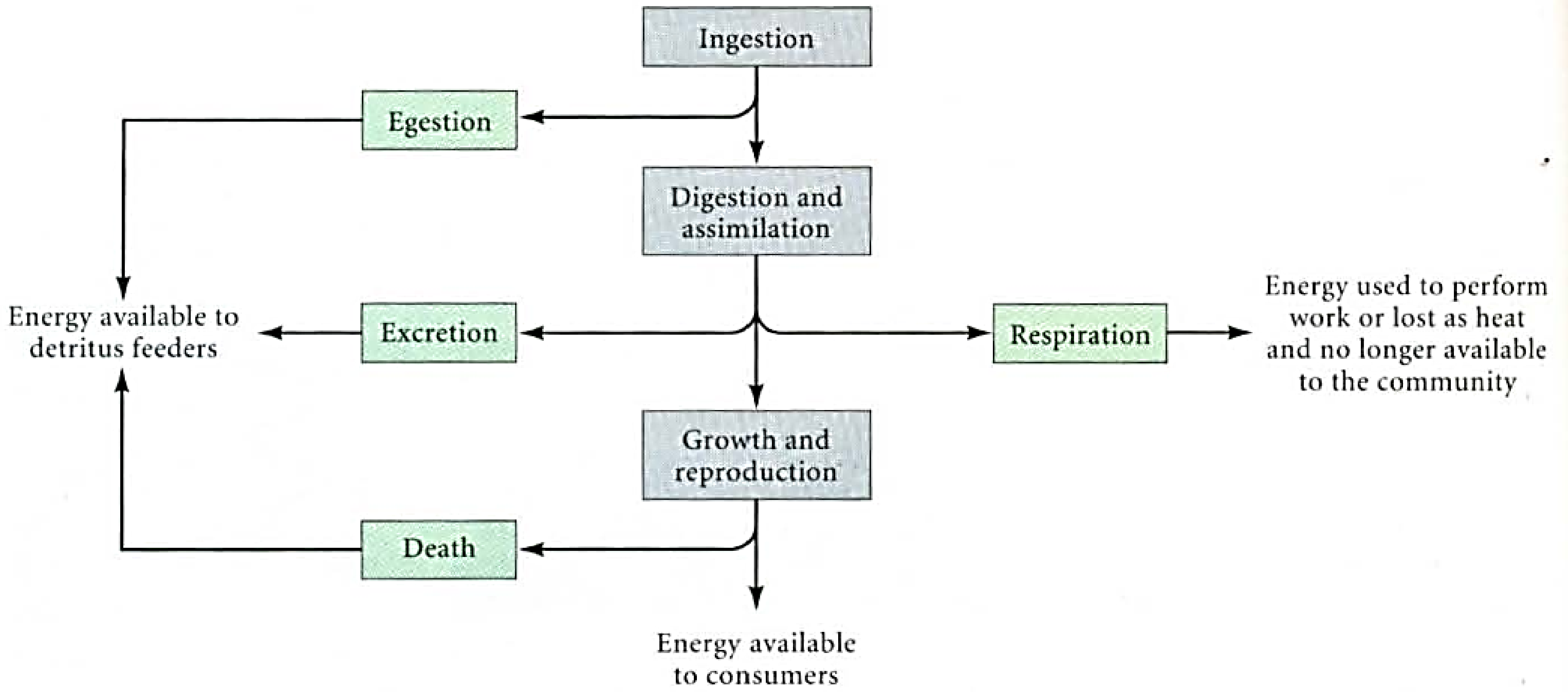
- Secondary supplement of energy to an ecosystem called **energy subsidy**. For example wind and rain in a rainforest, tidal energy in estuary, fossil fuel/fertilizer/human energy in agroecosystem.
- Excess loss of energy from an ecosystem called **energy drain**. Example: harvest, pollution, climatic stresses.
- Energy produced inside the ecosystem called **autochthonous energy**.
- Energy imported from the other ecosystem called **allochthonous energy**.
- The ecosystem which exports energy called **source**, while the ecosystem which imports energy called **sink**.

Ecological efficiencies

- **Ecological efficiencies:** Percentage of energy transferred from one trophic level to the next trophic level, called ecological efficiency between the two trophic level.



Ecological efficiencies



Ecological efficiencies

- **Photosynthetic efficiency** is the percentage of solar energy converted to the net primary production.
- **Consumption efficiency (CE):** Percentage of total productivity available at one trophic level (P_{n-1}) that actually consumed (I_n) by a trophic compartment one level up. $CE = \frac{I_n}{P_{n-1}} \times 100$
- **Assimilation efficiency (AE):** It is the proportion of ingested energy that is assimilated in percentage. $AE = \frac{A_n}{I_n} \times 100$
- **Production efficiency (PE):** The proportion of assimilated energy that is incorporated as new biomass. $PE = \frac{P_n}{A_n} \times 100$
- **Gross Production efficiency =** $AE \times PE = \frac{P_n}{I_n} \times 100$
- **Ecological efficiency =** $CE \times AE \times PE = \frac{P_n}{P_{n-1}} \times 100$

Ecological efficiencies

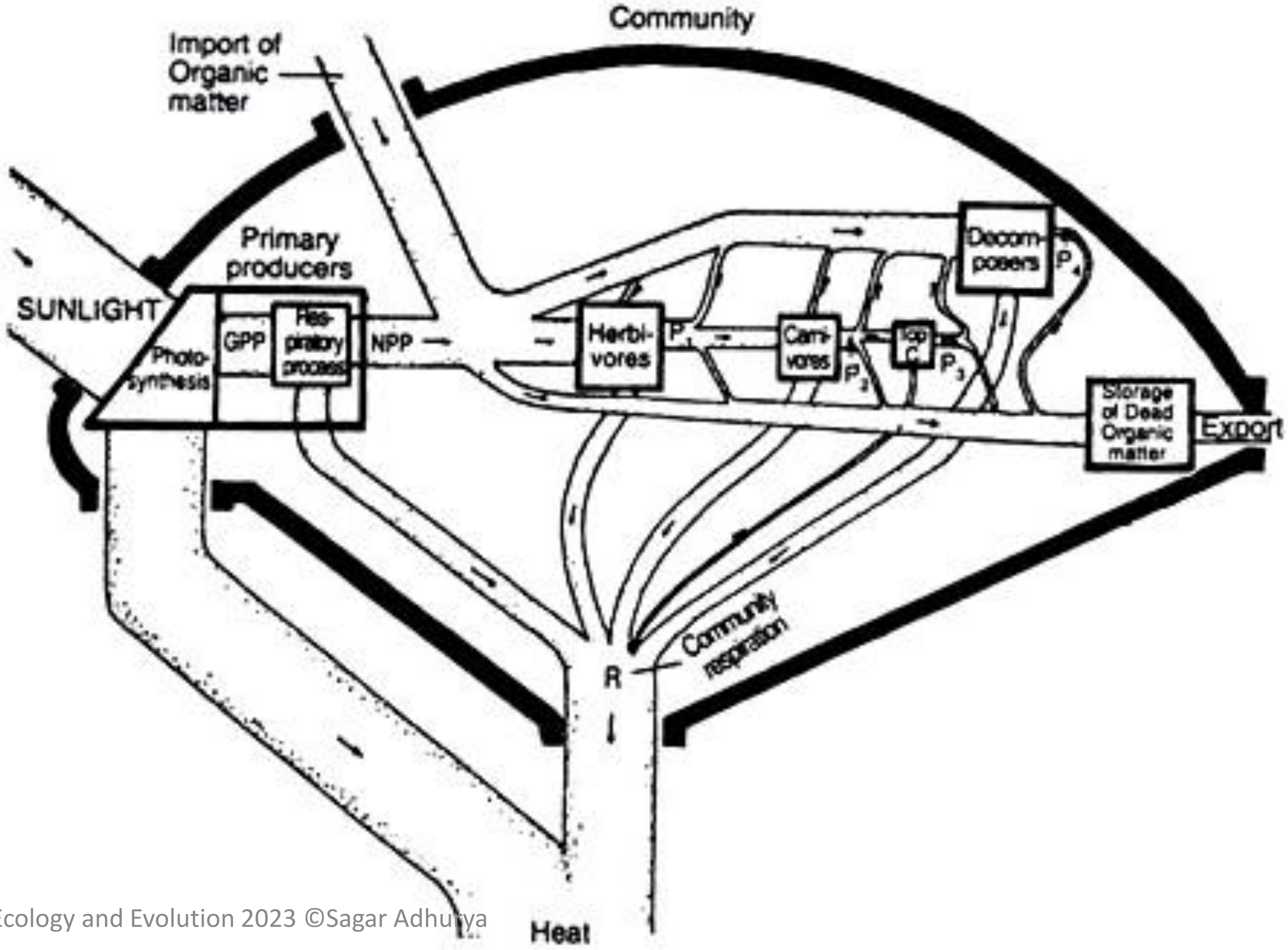
- Assimilation efficiency is 100% for microorganism in most cases where digestion is extracellular and no faeces are produced.
- Assimilation efficiencies for $herbivore, detritivore\ and\ microbivore(20-50\%) < insectivore(70-80\%) < carnivore\ (90\%)$
- Assimilation efficiencies for different plant food: $decaying\ wood\ by\ microorganisms\ (15\%) < Large\ twig\ of\ willow\ by\ mountain\ hare\ (31\%) < small\ twig\ of\ willow\ by\ mountain\ hare\ (35\%) < young\ vegetation\ (60-70\%) < seeds\ (80\%)$
- Greater the fiber content (cellulose, lignin) of plant materials, less assimilation.
- Production efficiencies of endotherm (1-2%) <ectotherm(10%)
- PE increases with size in endotherms while PE decreases with size in ectotherms.
- Microorganisms with rapid growth has highest PE.
- PE of herbivore>carnivore

Characteristics of energy flow

- Unidirectional
- Progressive decrease in energy
- Respiratory loss is higher in higher trophic level
- Higher assimilation efficiency at higher trophic level
- Large amount of energy always remained in ecosystem as unutilised as standing crop
- Energy flow in ecosystem follows the laws of thermodynamics.
- Unlike nutrients, the energy is not cycled within ecosystem.

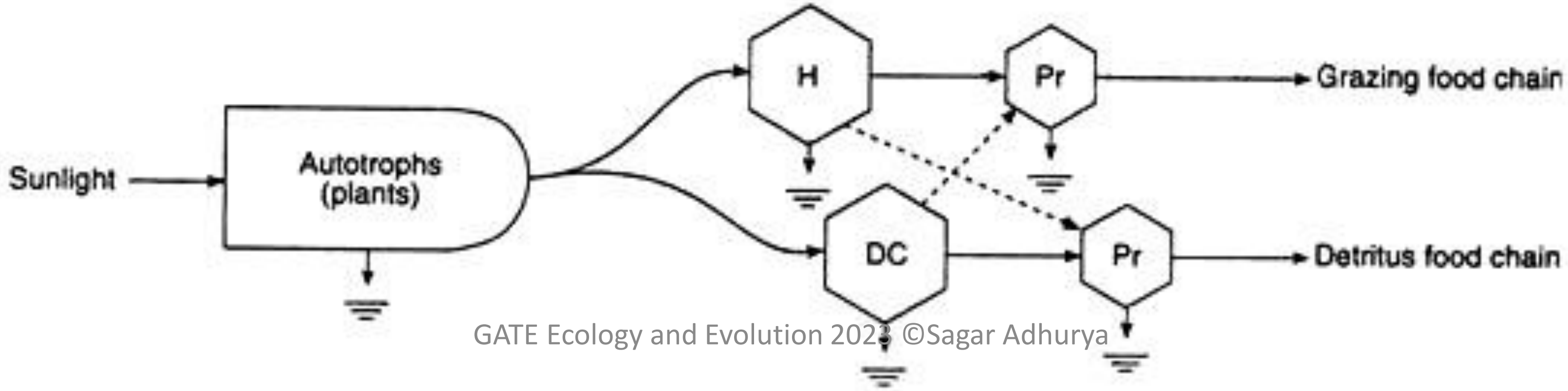
Models of energy flow

- The single channel energy flow model by HT Odum in 1956



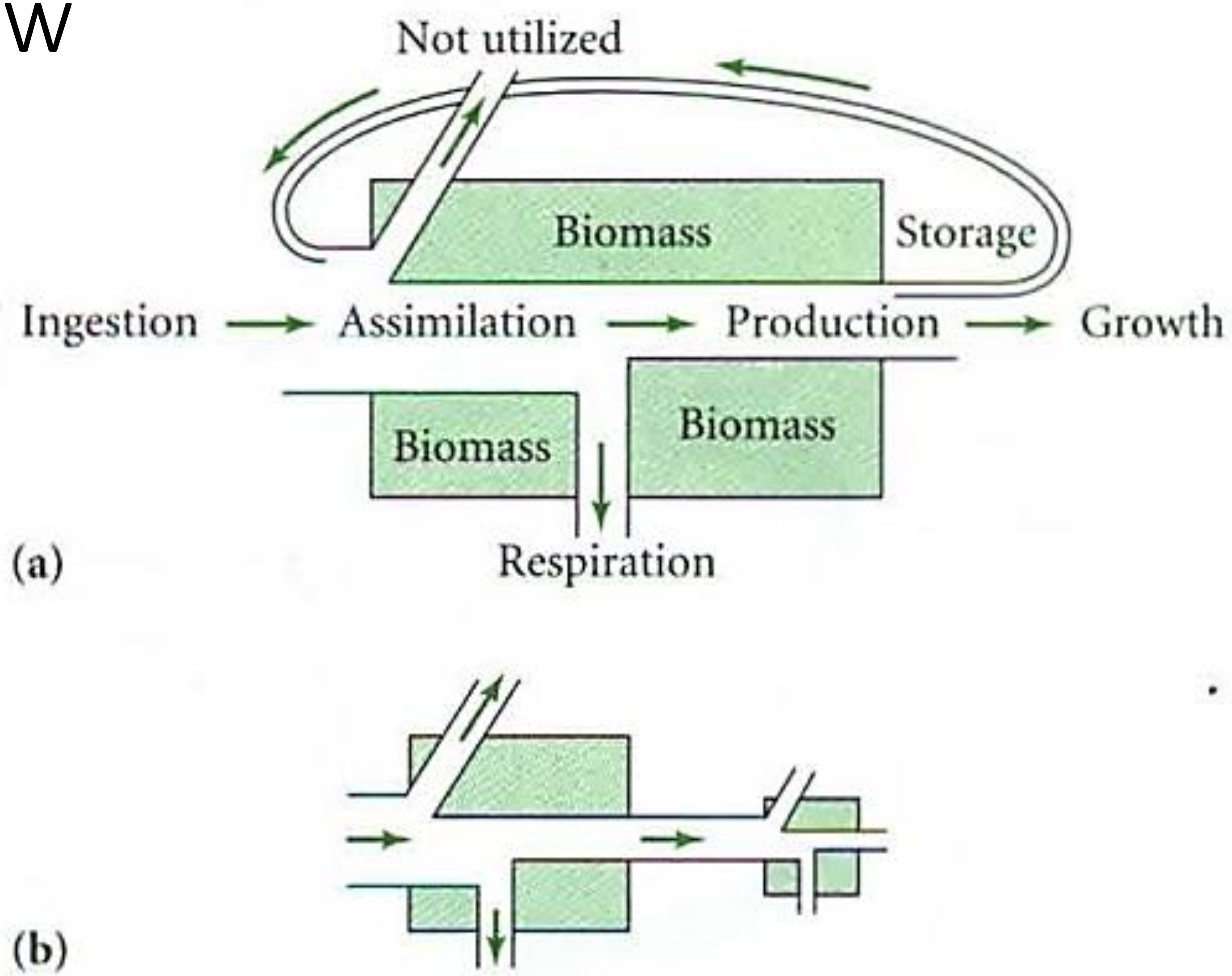
Models of energy flow

- **Y-shaped energy flow model:**
  - It relates to the basic stratified structure of ecosystem;
  - The direct consumption of living plants and dead organic matter are usually separated in both time and space; and
  - The macro consumers and micro consumers differ greatly in size-metabolism relations and in the techniques required for studying
- Energy flow through heavily grazed pastures or grassland shows larger energy flow via grazing food chain
- Detrital food chain is much important for forest, marshes and oceans.



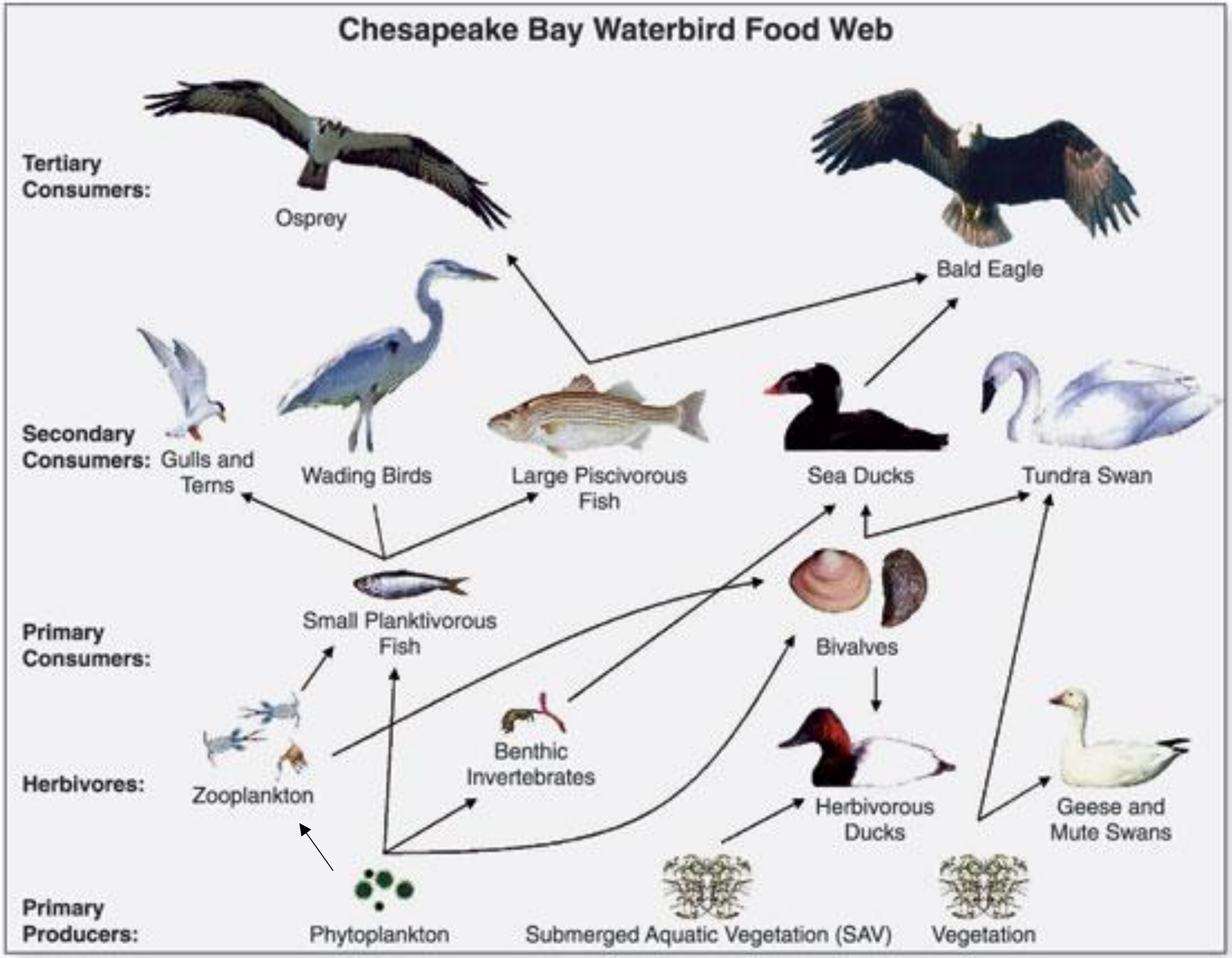
Models of energy flow

- **Universal model**
  - It is called “universal” because it is applicable to any living component which may be plant, animals, microbes, individual, population or trophic group.
  - Proposed by EP Odum



Food chain and food web

- The interrelationship between plants and animal, and also animal and animal in the sphere of energy production and consumption results in a definite pattern of several stages of eating and being eaten up – referred as **food chain**.
- Food chains are not isolated rather interconnected. Interconnected food chains together form a **food web**.



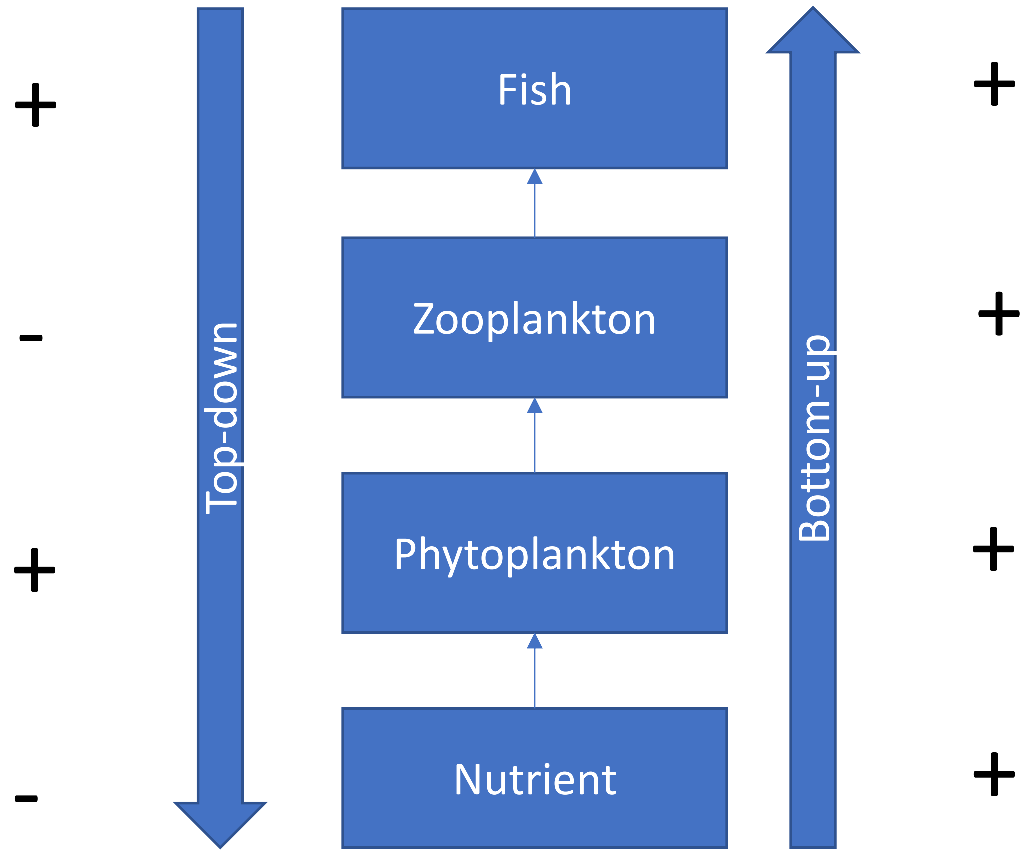
Types of food chain

- **Grazing food chain:**
  - Here the size of individuals usually increase in size from small to large.
  - Example: Grass → Goat → Man
- **Parasitic food chain:**
  - Here organisms tend to decrease in size as one goes higher up the food chain.
  - Example: Mammal → Fleas → *Leptomonas sp.*
  - Parasitic food chain are usually shorter than grazing food chain because metabolism per gram increases sharply with the next trophic level.
- **Detrital food chain:**
  - It passes from dead organic matter to microbes, then detritivores and subsequently to their predators.

Why food chain is relatively short?

- **Energetic hypothesis:** Length of the food chain is limited by the inefficiency of energy transfer along the chain. Approximately, 10% of the energy stored at one trophic level is converted to organic matter of the successive trophic level.
- **Dynamic stability hypothesis:** Long food chains are less stable than short food chain. Population fluctuation at lower trophic level are magnified at higher level, sometime result in the local extinction of the top predator.

Top-down and bottom-up effect

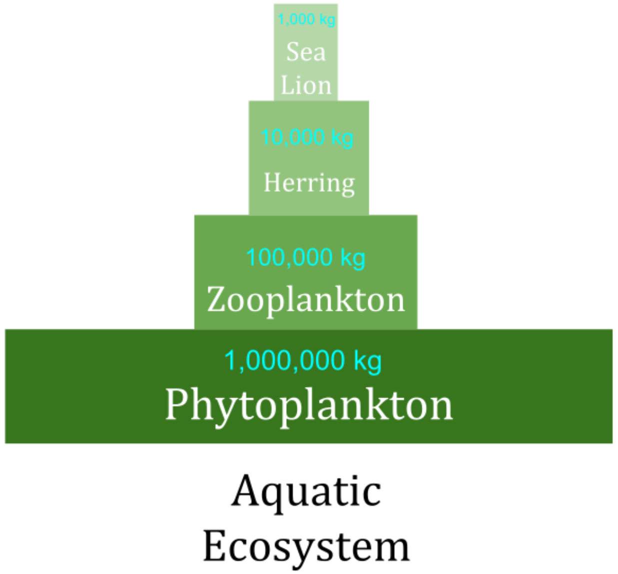


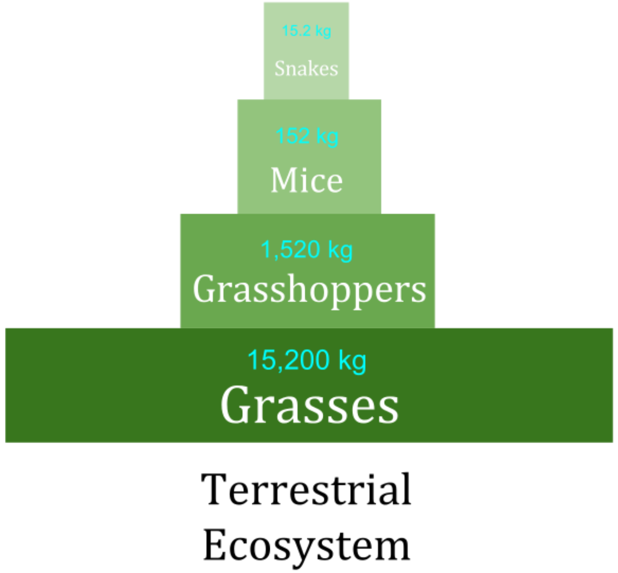
Ecological Pyramid

- An **ecological pyramid** is a graphical representation of the relationship between the different living organisms at different trophic levels. It was given by G.E. Hutchinson and R. Lindeman.
- A **pyramid of numbers** representing the number of individual organisms at each trophic level.
- A **pyramid of biomass** shows how much biomass (the amount of living or organic matter present in an organism) is present in the organisms.
- A **pyramid of energy** shows how much energy is retained in the form of new biomass at each trophic level. It is always upright.

Pyramid of numbers

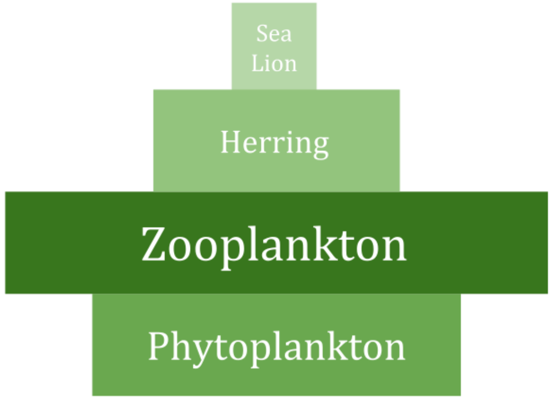
- This shows the number of organisms in each trophic level without any consideration for their individual sizes or biomass.
- The pyramid is not necessarily upright. For example, it will be inverted if beetles are feeding from the output of forest trees, or parasites are feeding on large host animals.



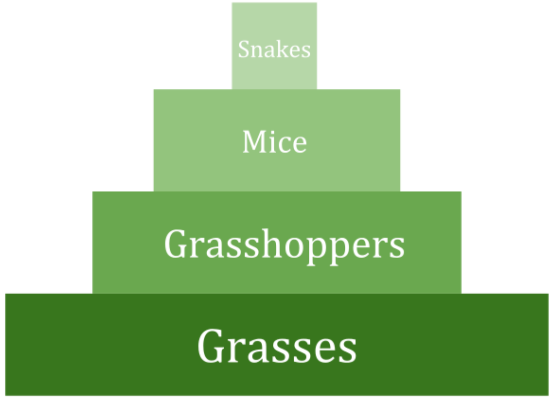


Pyramid of biomass

- It is a graphical representation of biomass (total amount of living or organic matter in an ecosystem) present in unit area in different trophic levels. Typical units are grams per square meter.
- The pyramid of biomass may be "inverted". For example, in a pond ecosystem, the standing crop of phytoplankton, the major producers, at any given point will be lower than the mass of the heterotrophs, such as fish and insects. This is explained as the phytoplankton reproduce very quickly, but have much shorter individual lives.



Aquatic Ecosystem



Terrestrial Ecosystem

Pyramid of Energy

- The energy pyramid is always upright!