Lecture-1: ESI101: B Tech – II Semester

Evolution, Ecology, and Ecosystem

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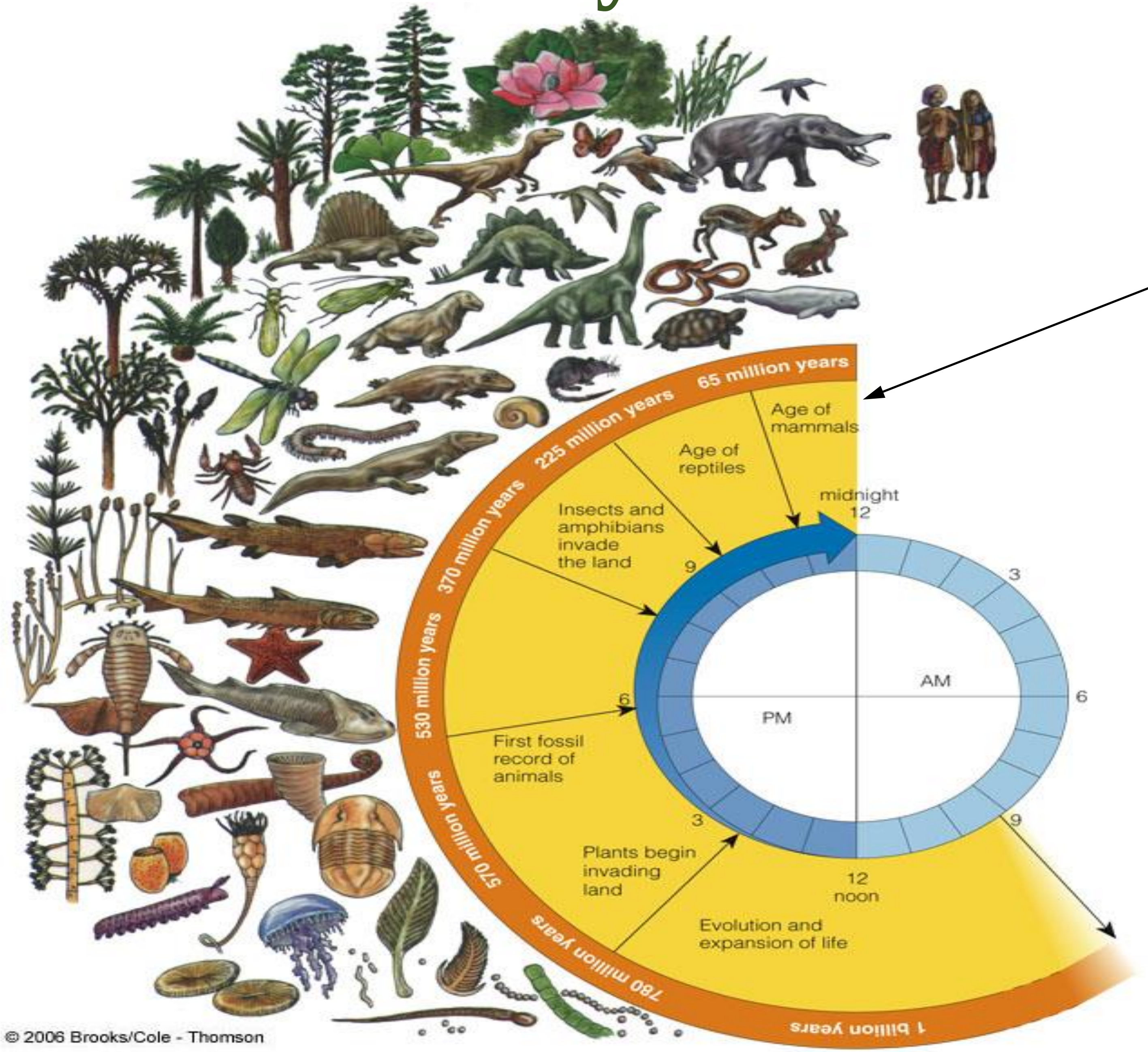
Part-I: Ecosystems and Evolutions



Modern humans
(Homo sapiens)
appear about
2 seconds
before midnight

Origin of life
(3.6–3.8 billion
years ago)
(Chemical
Evolution)

Evidence of
Life= 900
million yrs ago

Fig.1: Evolution of life

Ecosystem:

•Term coined by **A.G. Tansley**

•Eugene P. **Odum defined** ecosystem as **“any unit that includes all the organisms that function together** 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 into biotic and abiotic parts.**

•Ecosystem is the **structural and functional unit of biosphere.**

•For example: **Forest ecosystem.**

Individual (Species) → Population → Community → Ecosystem → Biome → Biosphere

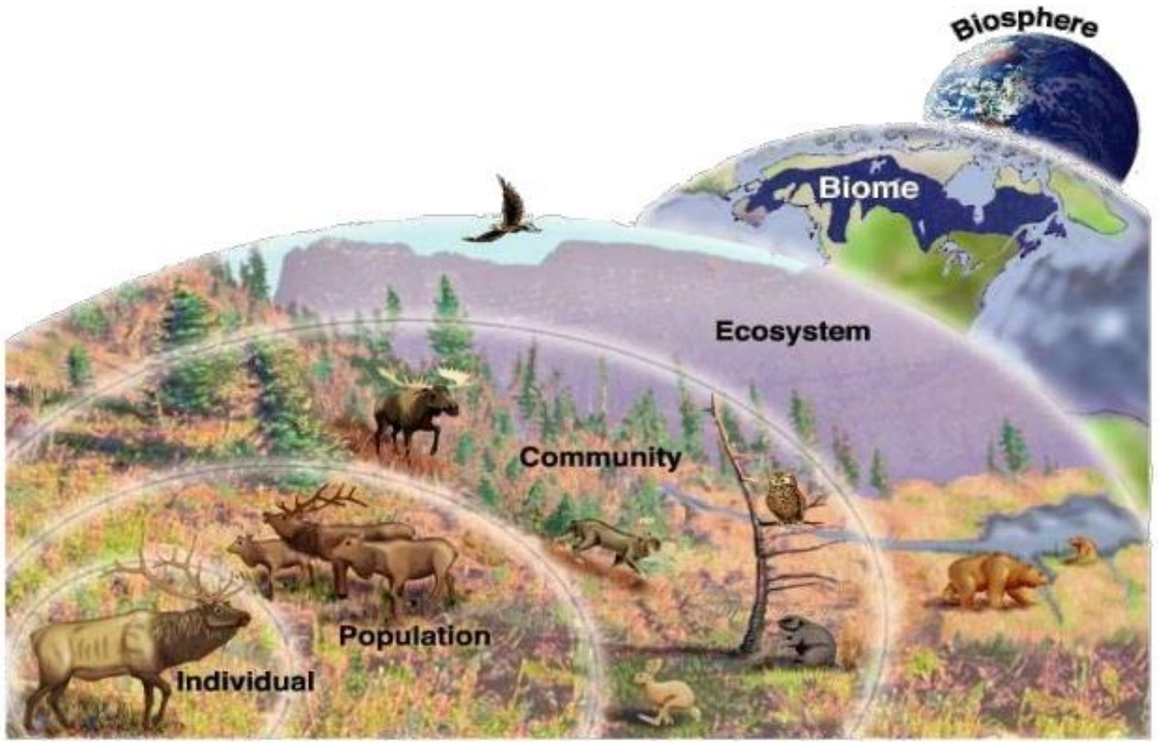
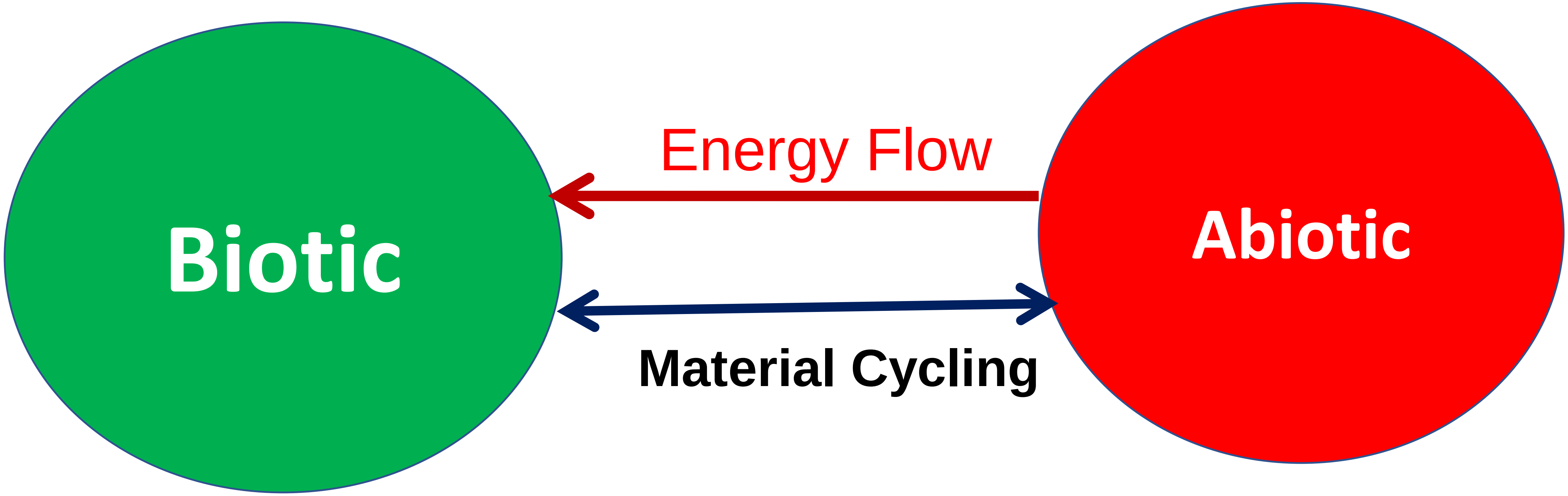


Fig. 2: Hierarchical Levels of Organization in Ecology

The interaction between biotic and abiotic components is known as "Ecology".

- Ecology is the branch of biology that "studies how organisms interact with their environment and other organisms".



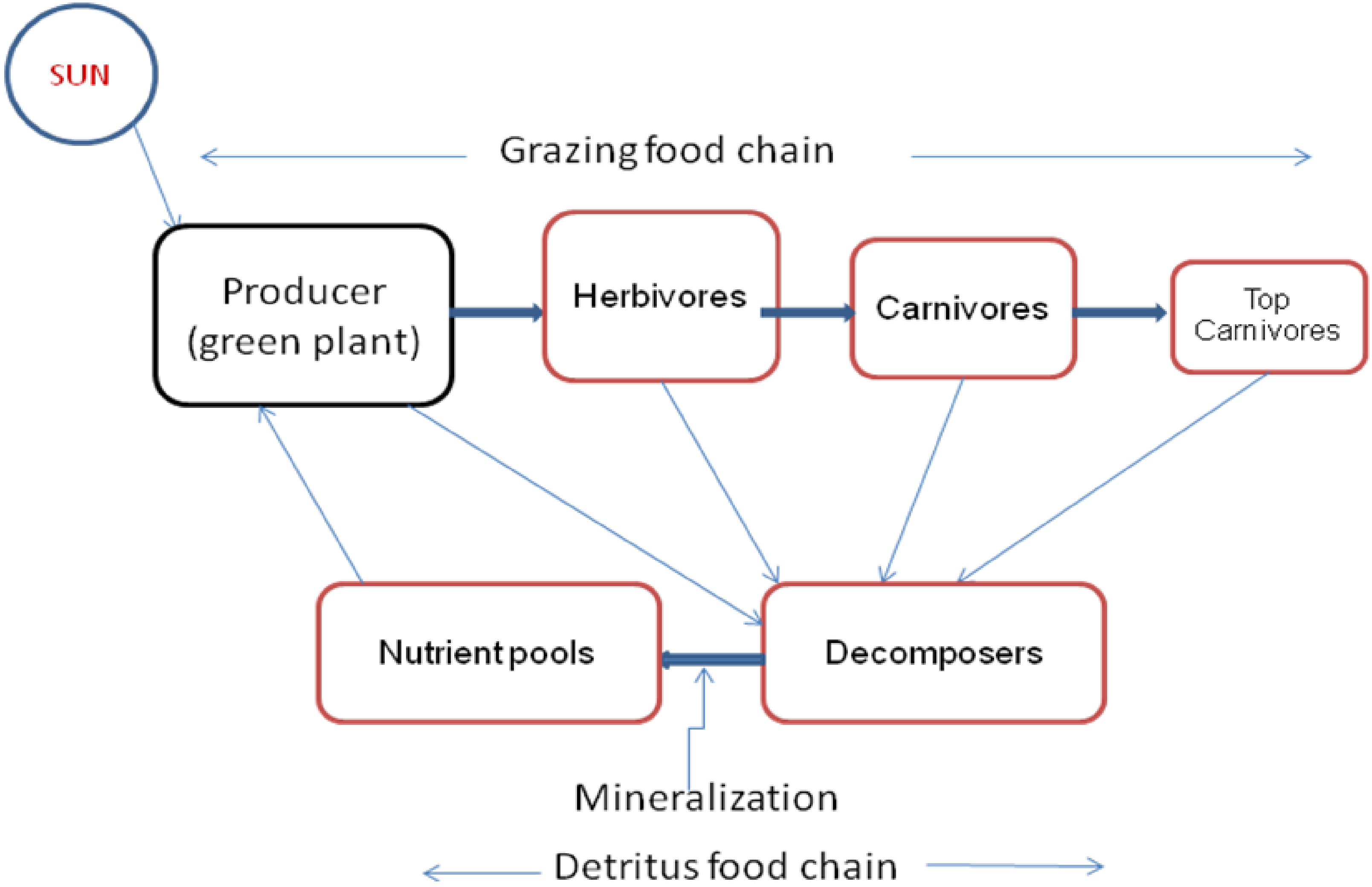
Abiotic factors

Abiotic factors of interest include:

1. **Sunlight**
2. **Temperature (range from 0 to 45 ^{0}C)**
3. **Water**
4. **Wind (increases heat & water loss)**
5. **Rocks and soil**

Ecosystem

- All the organisms living in an area and the nonliving features of their environment



2. Biotic component:

Living factors influencing the ecosystem

➢Producers/Autotrophs:

Chlorophyll-bearing and self-nourishing organisms. E.g: all green plants.

➢Consumer/heterotrophs:

Dependent on the producers for their food. E.g.: herbivores, carnivores and omnivores.

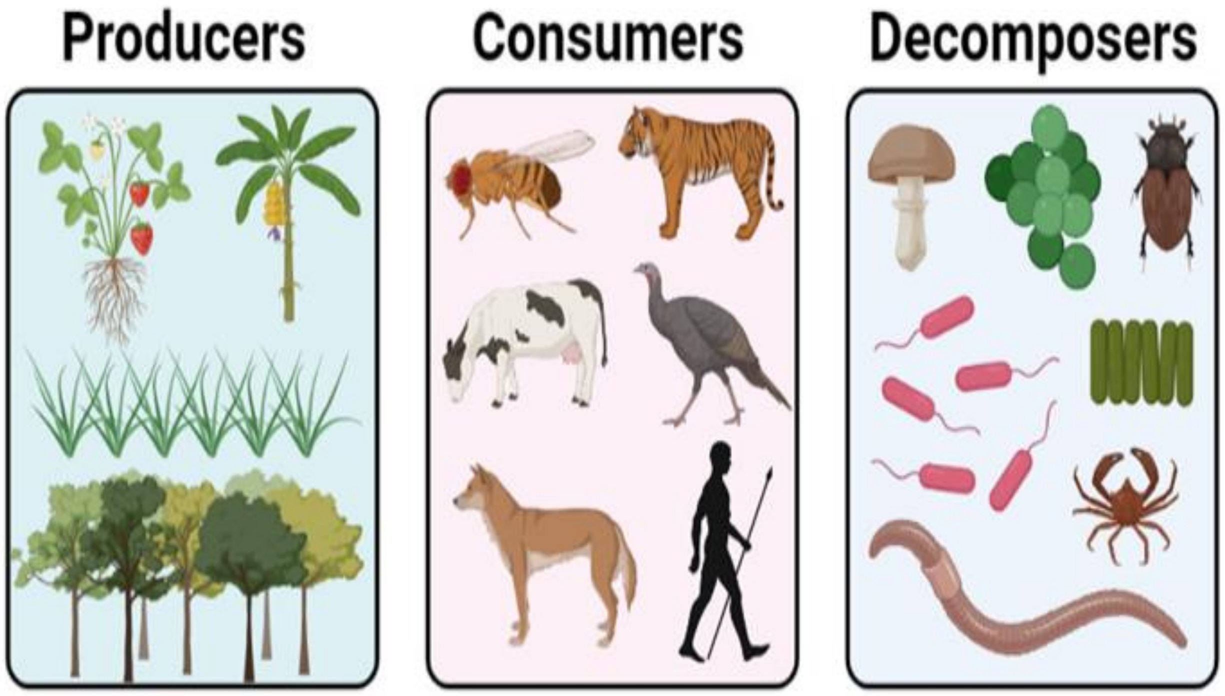
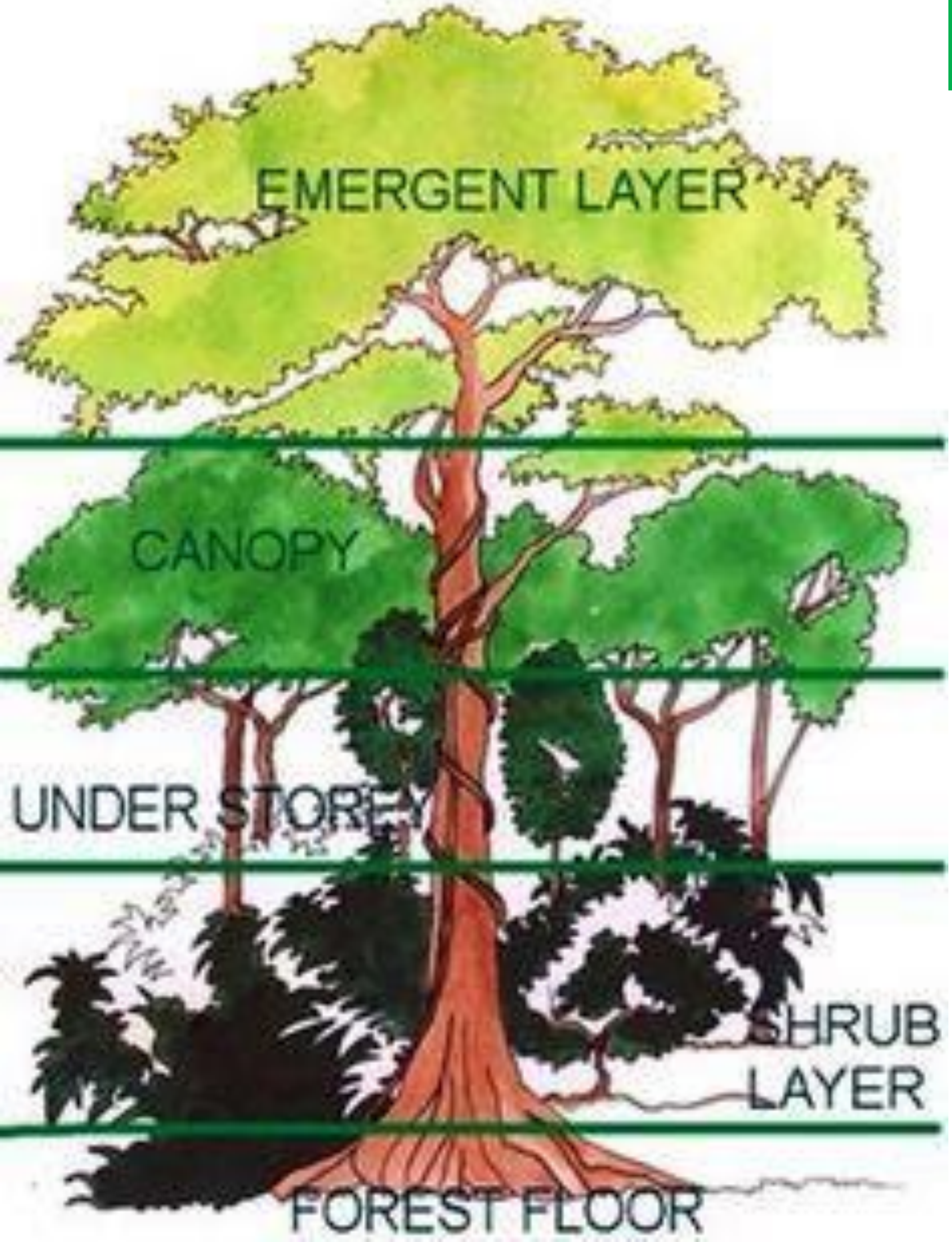
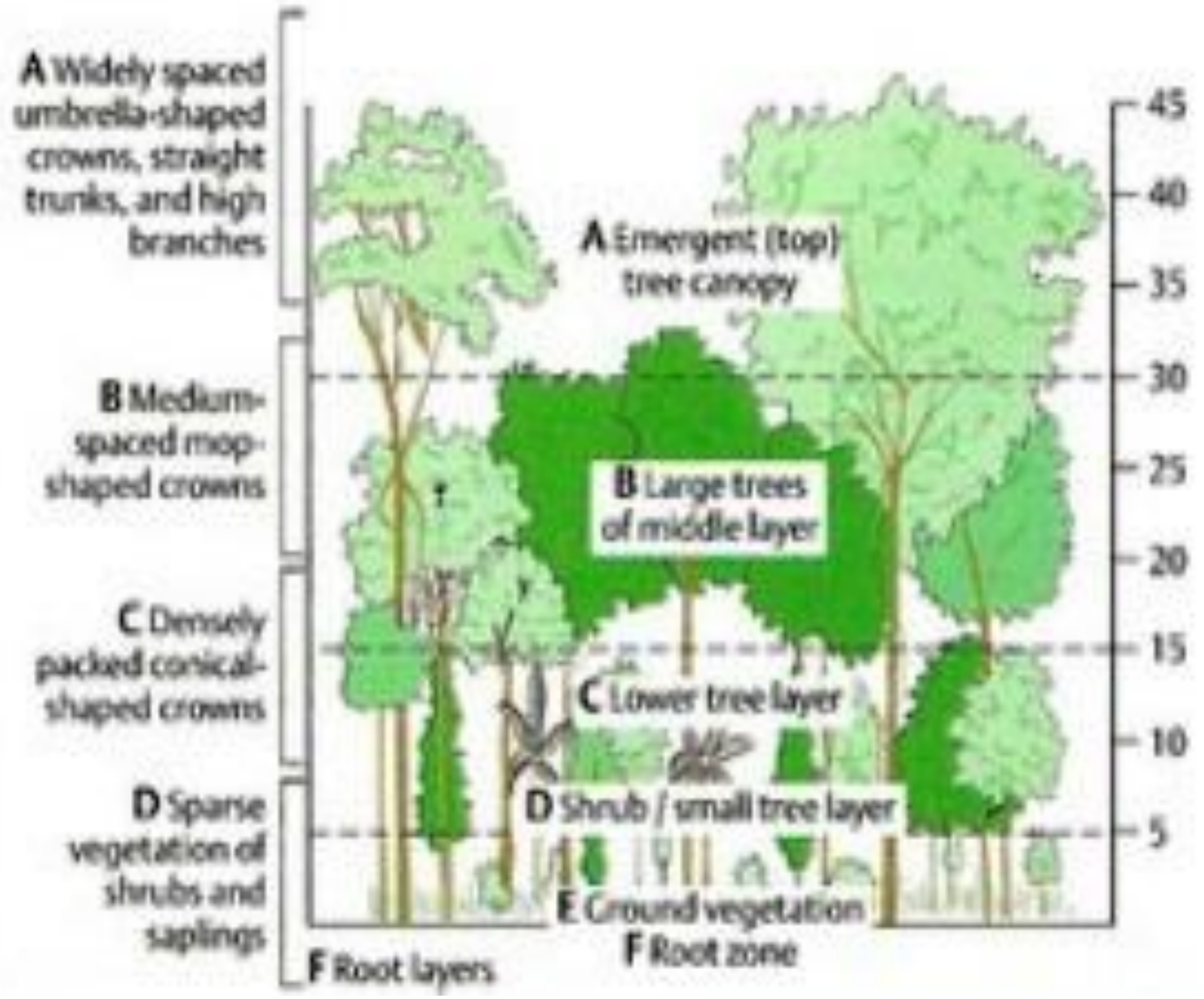


Fig. 5: Biotic components of the Ecosystem

Decomposers: **Derive energy from dead and decayed organisms.** E.g.: bacteria and fungi.

Producers


EMERGENT LAYER
CANOPY
UNDER STOREY
SHRUB LAYER
FOREST FLOOR


A Widely spaced umbrella-shaped crowns, straight trunks, and high branches
B Medium-spaced mop-shaped crowns
C Densely packed conical-shaped crowns
D Sparse vegetation of shrubs and saplings
F Root layers
A Emergent (top) tree canopy
B Large trees of middle layer
C Lower tree layer
D Shrub / small tree layer
E Ground vegetation
F Root zone
45
40
35
30
25
20
15
10
5

Functions of Ecosystem:

- **Flow of energy**
- **Nutrient Cycling**

Nutrients Cycling:

- **Producers use the nutrients** to prepare their food, the **consumers consume it and the decomposers recover the nutrients.**

- These **nutrients keep flowing** between **biotic & abiotic components**, thus forming a **nutrients cycle known as** the **biogeochemical cycle**.

- The **biogeochemical cycle involves** the **movement of elements** and compounds among the **land (lithosphere), organisms, air (atmosphere), and the oceans (hydrosphere).**

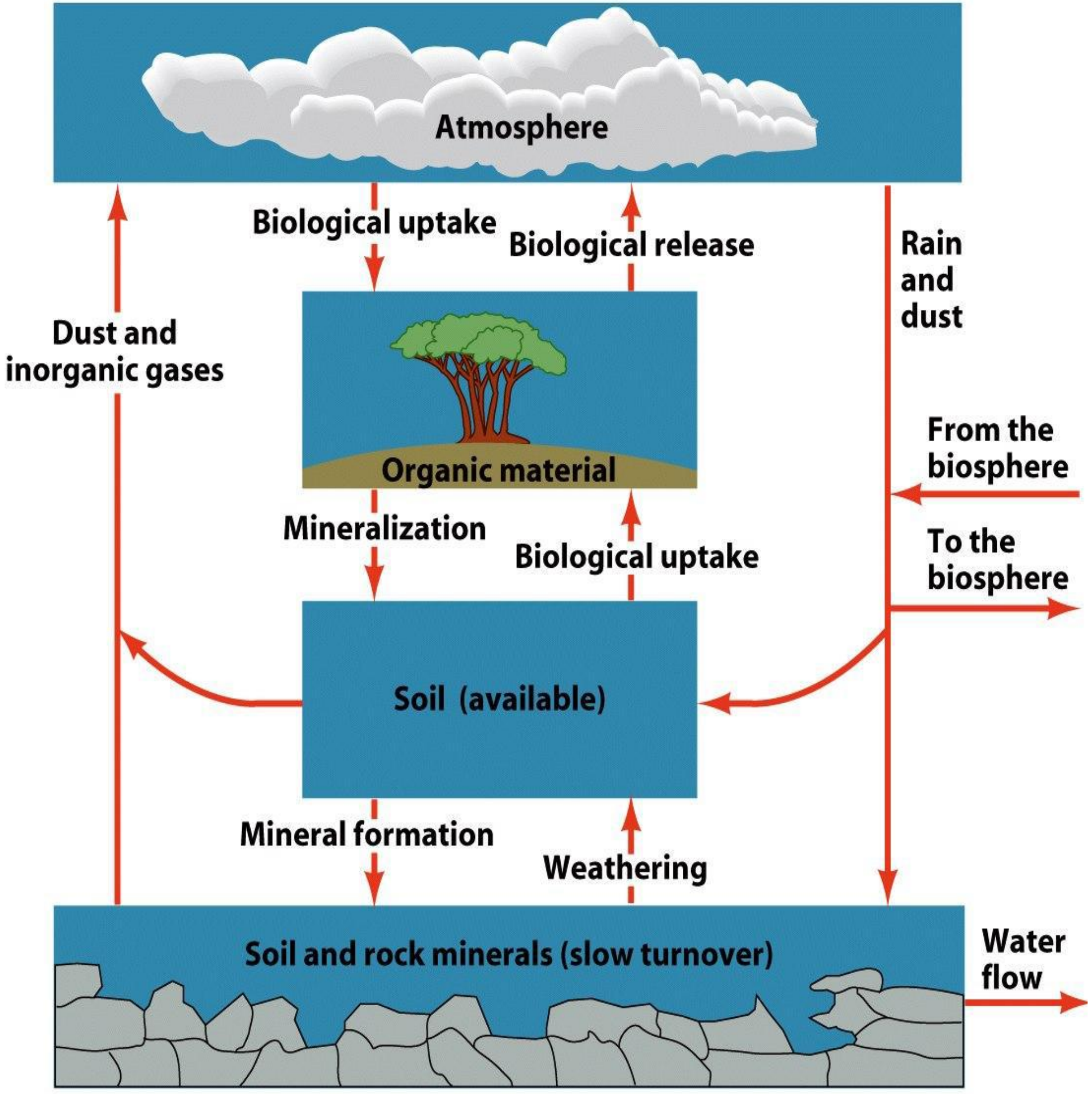


Fig. 6: Nutrient Cycling

Types of Biogeochemical cycles

Gaseous Type
Reservoir is in the atmosphere and Hydrosphere
E.g.: Carbon Cycle, Nitrogen Cycle

Sedimentary Type
Reservoir is in the lithosphere (Land)
E.g.: Sulphur cycle, Phosphorus cycle

Food Chain, Food Web & Tropic Level

Energy flow in an ecosystem is a one way process

Larger the number of species in food web, the more "stable" the community, because the greater number of alternate pathway of energy flow".

➢ If one species is vanished by stress, a predator had more feeding options in a species rich food web rather than a species poor one.

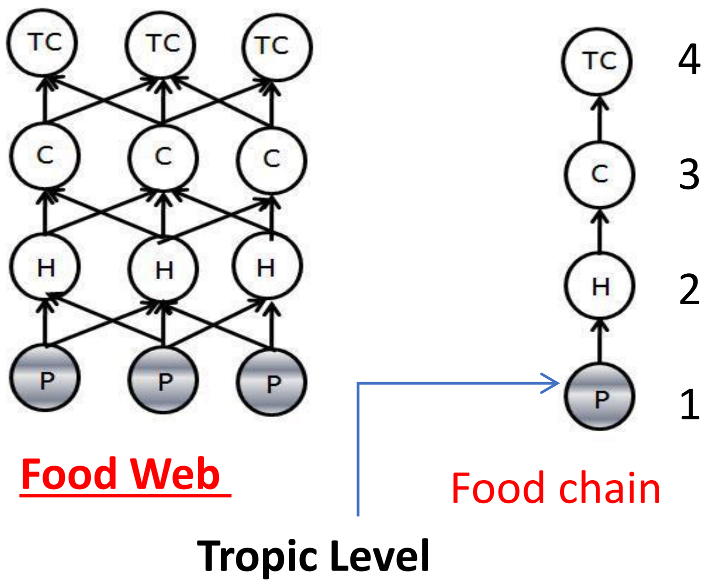


Fig. Simple food chain and a food web.
P= producer,
H= hervivores,
C= carnivores and
TC= top carnivores.

Food Web:

- **Long interlinked food-chain processes** in an ecosystem.
- Represents **all possible feeding relationships** among various organisms of the ecosystem.
- **Little disturbance** in the chain leads to the **loss of species and the breakdown of the web.**

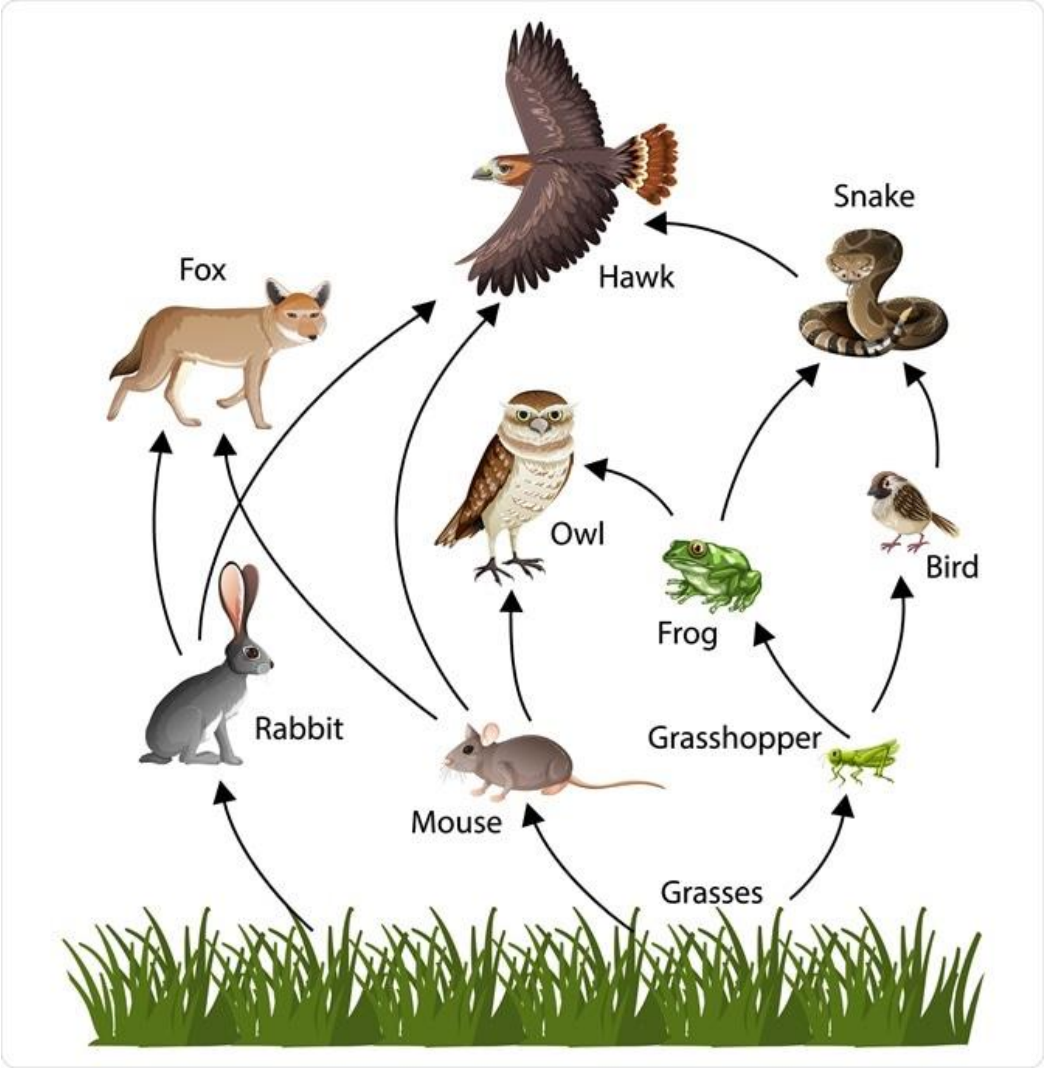


Fig.8: Food web

Biomagnification:

- Refers to the **increase in the concentration** of the toxicant at **successive trophic levels**.
- Result of **bioaccumulation.**
- Well known for **mercury and DDT.**

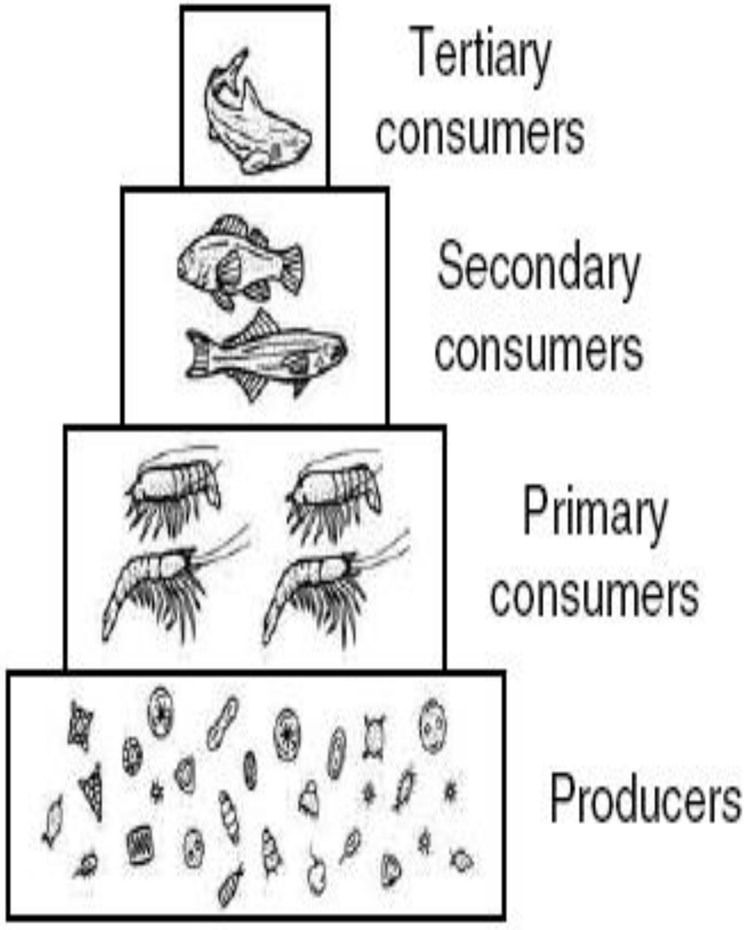
Trophic Level

Trophic Levels—each step in a food chain or food web

1. Level 1—**Producers** (autotrophs)
2. Level 2— **Primary** Consumers (**herbivores**)
3. Level 3—**Secondary** Consumers

   (**carnivores or omnivores**)
4. Level 4—**Tertiary** Consumers

(carnivore—usually **top carnivore**)



Energy Flow: Food Chain

The **process of eating and being eaten** by successive creatures is known as the food chain.

Types of Food Chain:

1. **Grazing food chain (GFC)**: **Starts from green plants** and **through carnivores it reaches the decomposers**. For example grassland ecosystems.

➢ **Restricted number of trophic levels** as the transfer of energy follows the **10% law** – only 10% of the energy is transferred to each trophic level from the lower trophic level (**Lindemann's law**).

Trophic level: Producers and consumers in an ecosystem can be arranged into **several feeding groups**, each one of them is known as **trophic level** (feeding level).

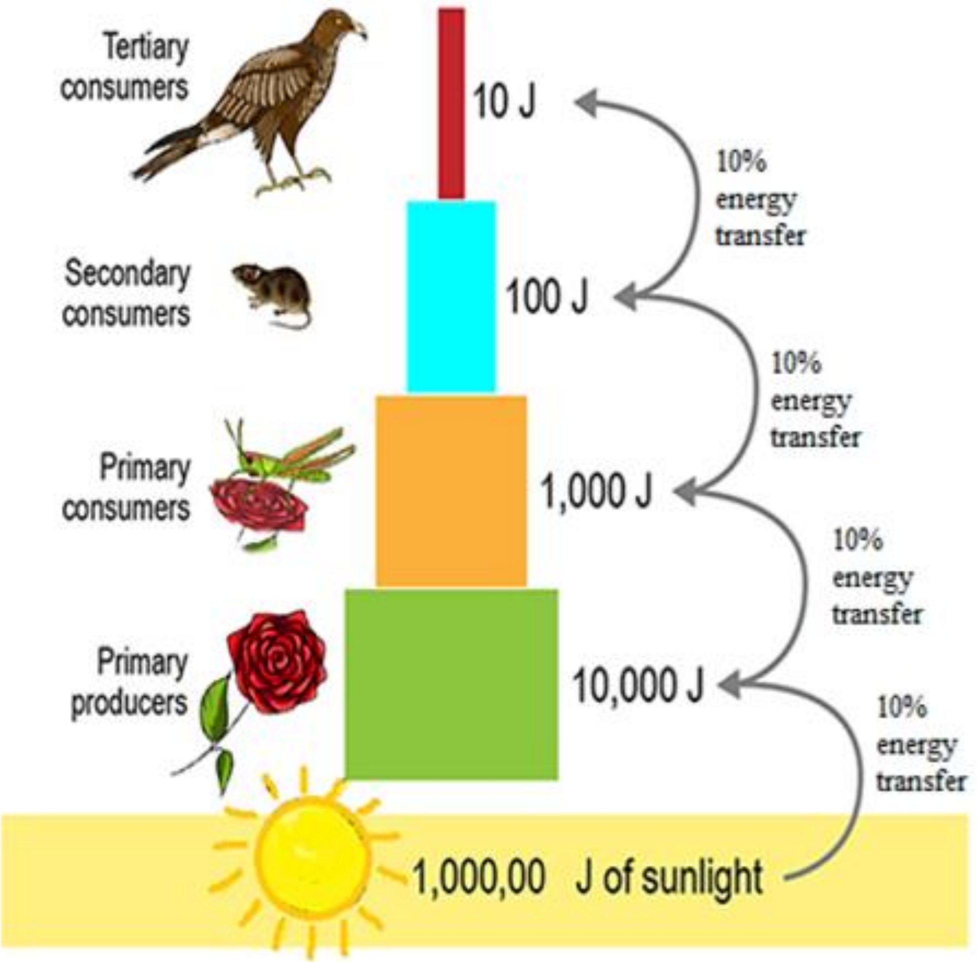


Fig. 7: Energy flow through different trophic levels (90% of the energy is lost as heat at each trophic level)

[1]. Grazing/predator food chain:

- **Producers represent the first trophic level (primary)**, **herbivore** represents the second (**secondary**), **primary carnivores** represents the **third trophic level (tertiary)**, and so on.

- **Starts from numerous organisms towards less numerous and larger organisms.**

Eg. Grass → grasshopper → frog → snake → hawk

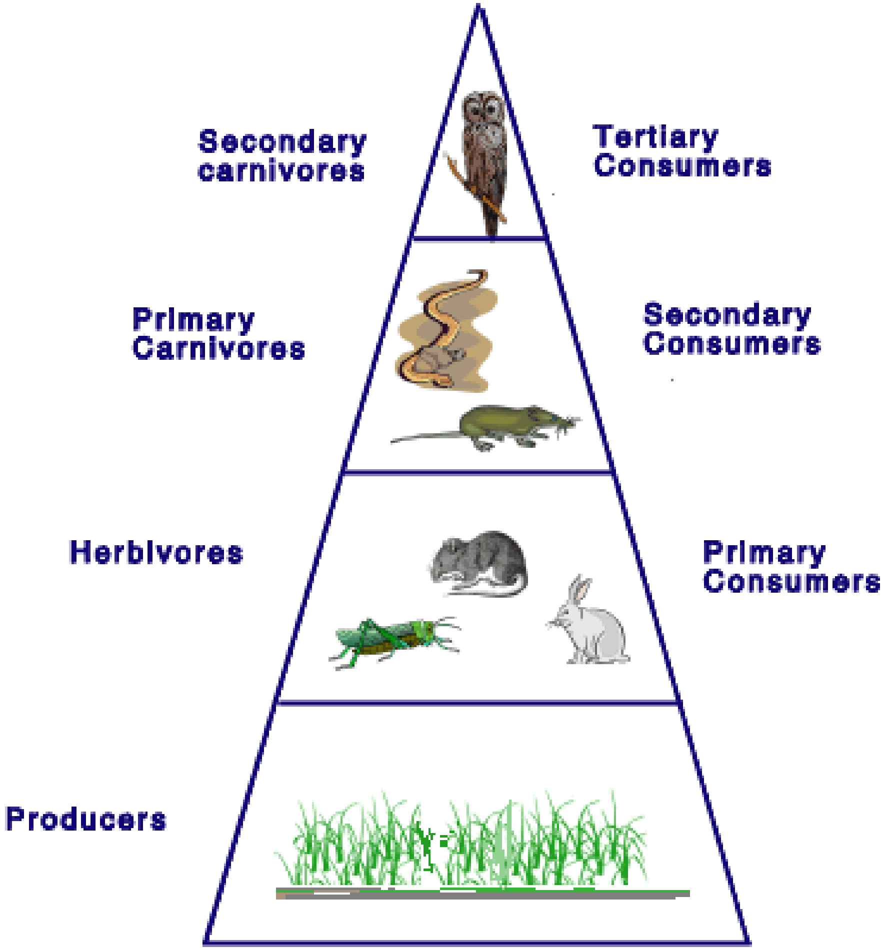
[2]. Saprophytic or detritus food chain: **Starts with dead organic matter**, then **progresses** to detritivores or **saprotrophs followed by their predators**.

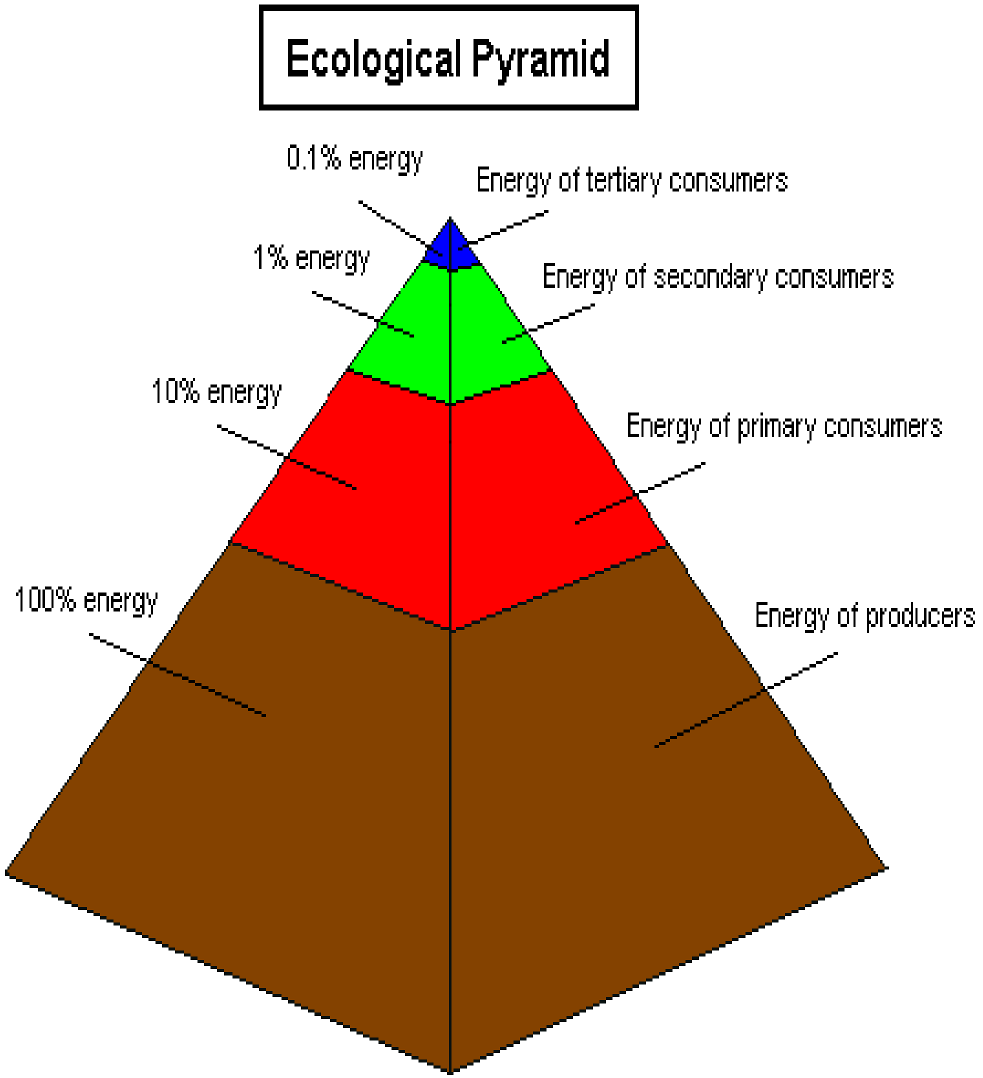
Eg. Dead animal/plant (dead organic matter) → maggot (small animals) → Bacteria/fungi

- It is made up of decomposers which are heterotrophic organisms (**saprotrophs**), mainly fungi, and bacteria.

Ecological Pyramids

- Diagram that shows the relative amount of **energy** or **organisms** contained within each **tropic level** of a food chain or web

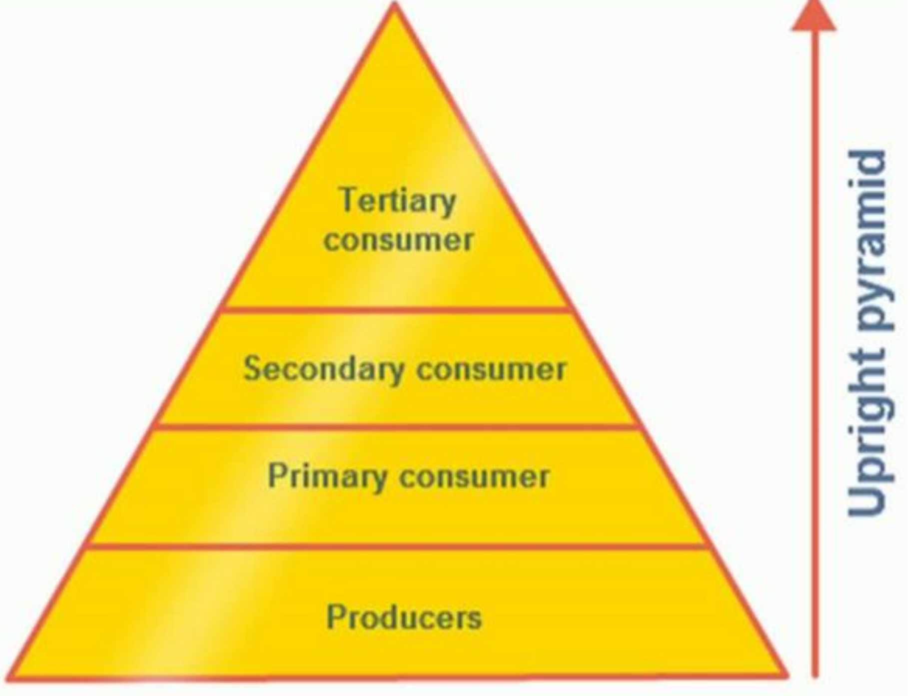




Ecological Pyramid:

- It is the **graphical representation of trophic relations** in an ecosystem for different parameters such as **food, energy, and biomass.**

- In most ecosystems, **all the pyramids of number, energy, and biomass are upright**; however, there are exceptions.



Three types of Pyramid:

[1]. Pyramid of number: **Depicts the number of individuals** at at different trophic levels

Ex. **Upright** (general food chain); **Rhombohedral/ inverted** (**forest ecosystem**: number of insects feeding on a big tree)

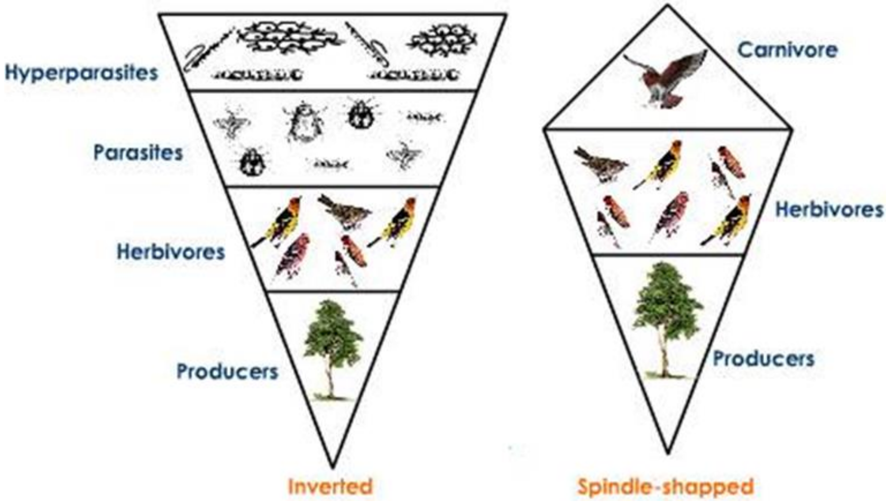


Fig. 10: Pyramid of Number

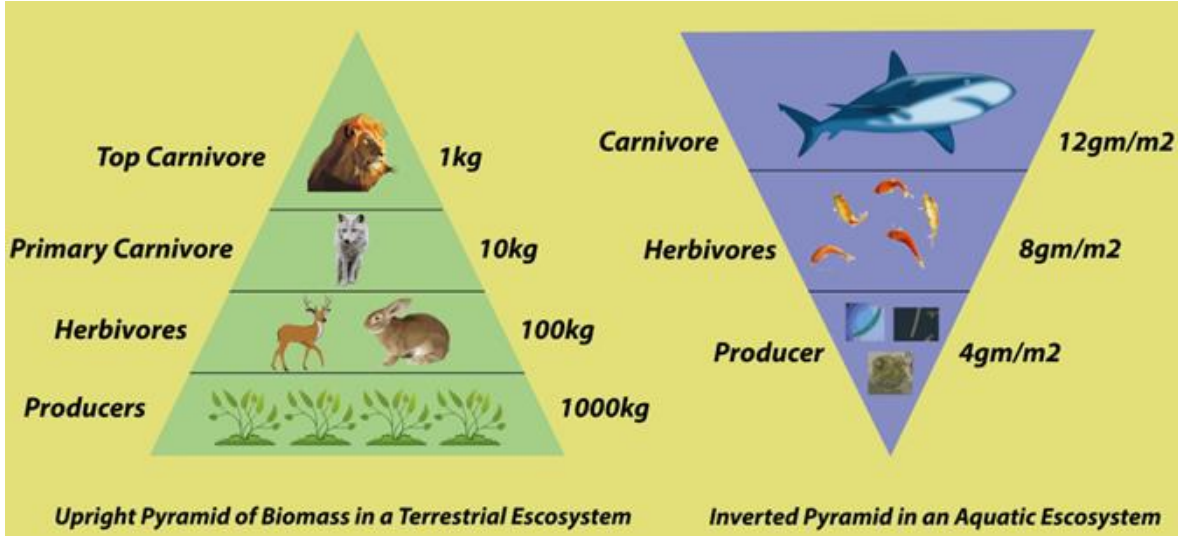
ii) Pyramid of biomass: When **each trophic level** is described in terms of **total biomass** or **weight of individuals**.

- Can be **upright or inverted.**

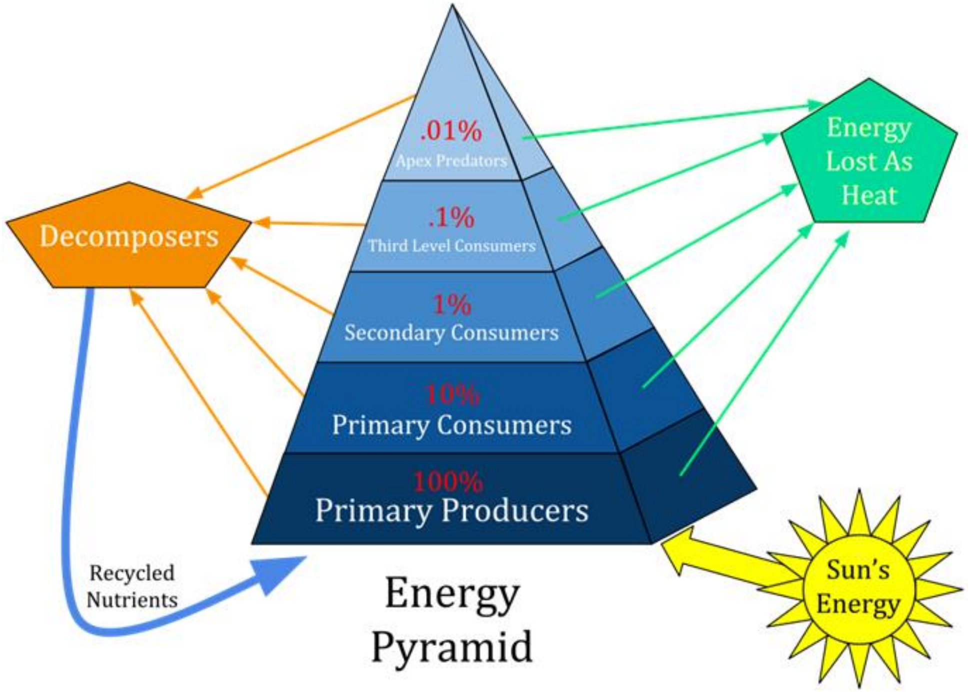
- Inverted pyramid of biomass in the aquatic ecosystem because the biomass of fish far exceeds that of phytoplankton.

iii) Pyramid of energy: When **each trophic level** is described in terms of the productivity or the **amount of energy** that passes through trophic levels

- **Always upright** as there is a **continuous loss of energy** at each trophic level.



(a)



(b)

Fig. 11 (a): Pyramid of biomass, (b): Pyramid of energy

Population Growth

- Population growth is **represented by the change in density of a population** which is the number of **individuals per unit area or volume.**

Population Change = (births + immigration) - (deaths + emigration)

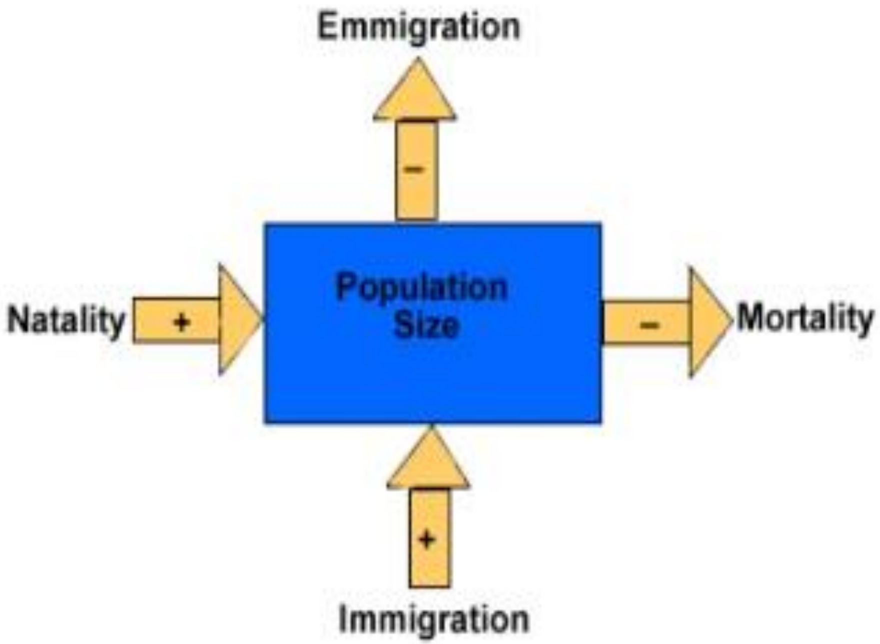


Fig.12: Factors influencing population density

Factors influencing population density:

Natality (birth rate)

Mortality (death rate)

Immigration

Emigration

Types of Population Growth

1. Exponential Growth curve (Growth Without Limit)

- **Occurs under ideal conditions** with unlimited resources.

$$\frac{dN}{dt} = (b-d)\times N \qquad\qquad \frac{dN}{dt} = rN$$

$r = b-d$

$$N = N_0 e^{rt}$$

Where, r is called the **Intrinsic Growth Rate or Malthusian Factor**

- **Example: Bacterial growth**

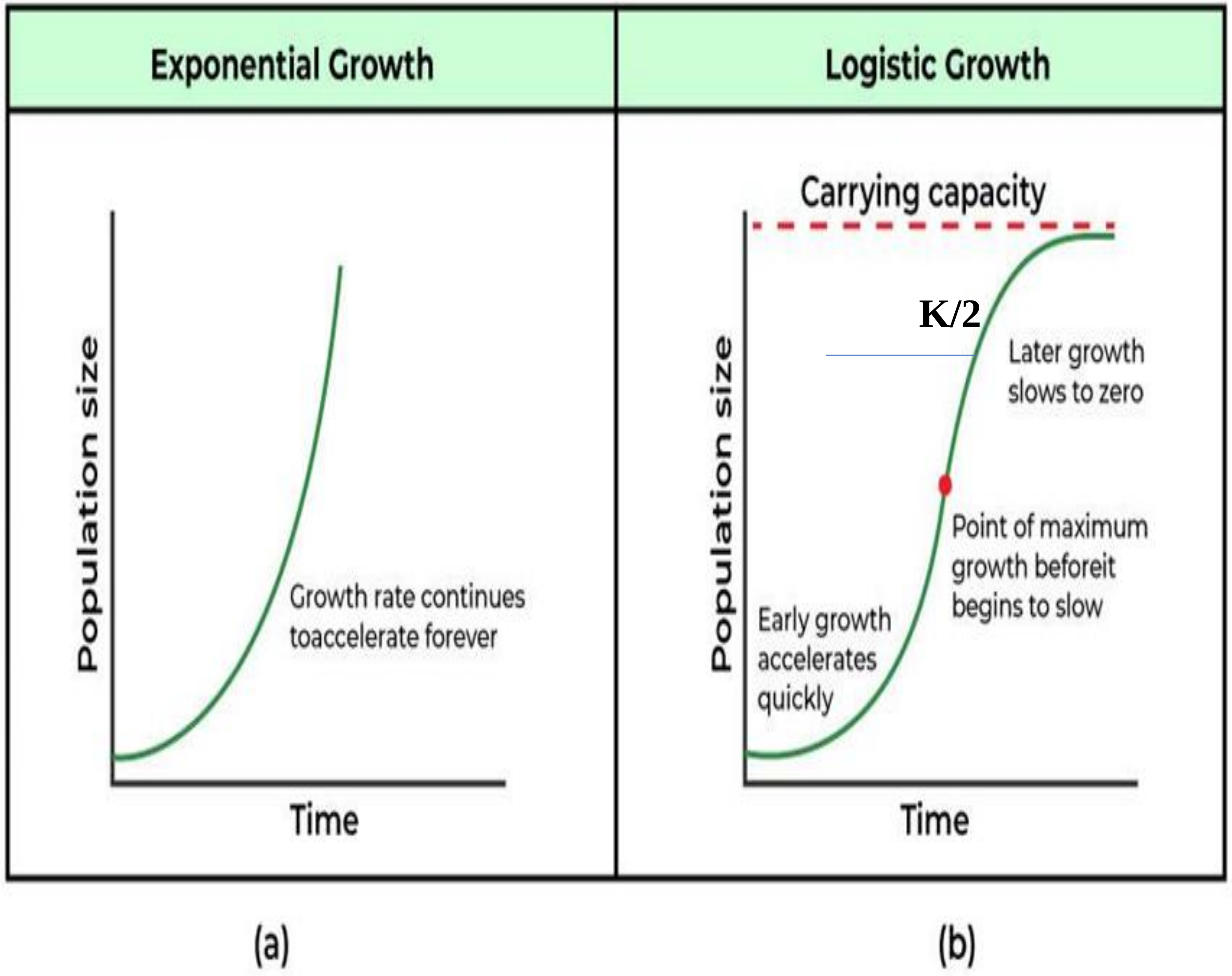


Fig. 13: Population growth models

Numerical

Suppose a population of butterflies is growing according to the logistic equation. If the carrying capacity is 500 butterflies and $r = 0.1$ individuals/(individual*month), what is the maximum possible growth rate for the population?

Solution: First determine N, i.e., population size.

From the plot of dN/dt vs. N, we know that the maximum possible growth rate for a population growing according to the logistic model occurs **when N = K/2**, thus N = 250 butterflies.

Now,

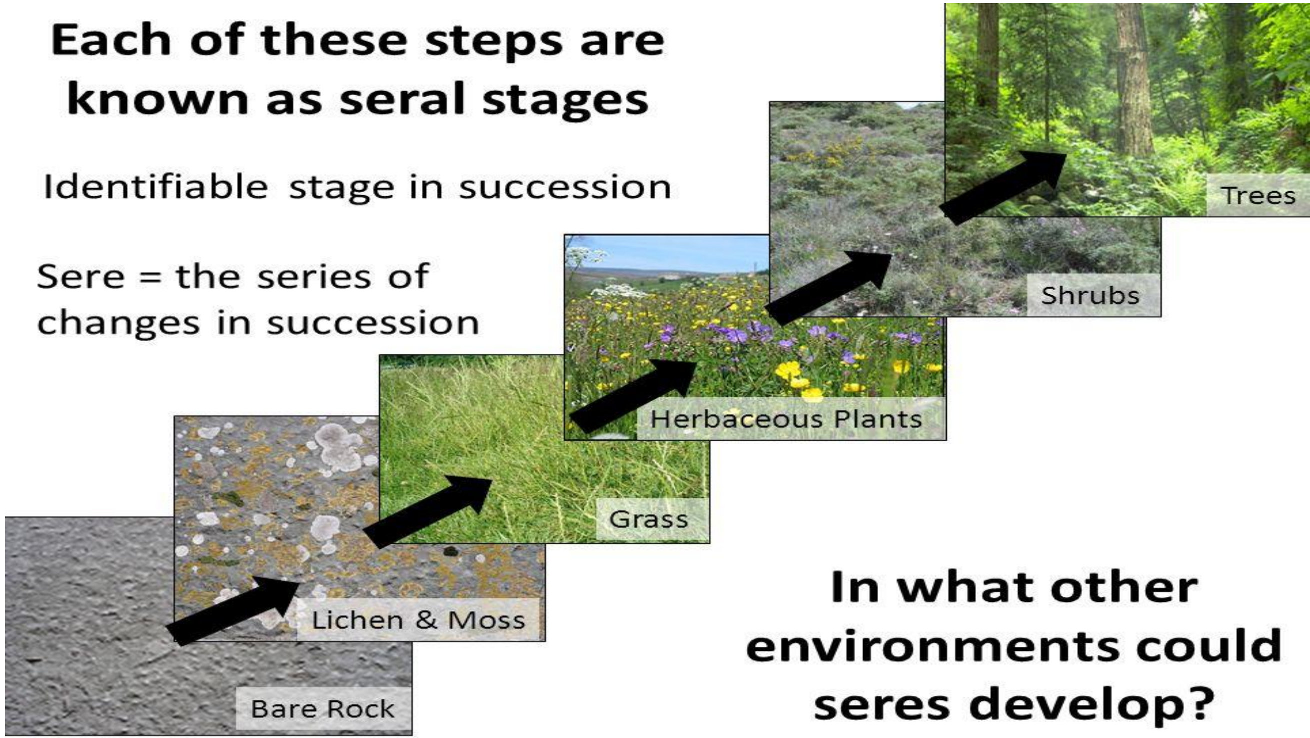
$dN/dt = rN [(1- N/K)]$

$= 0.1(250)[1-250/500)] = 12.5$ individuals / month

How ecosystem born? Succession and climax

- Pioneer species - A group of organisms, such as lichens, found in the primary stage of succession and that begin an area's soil-building process
- A seral community is an intermediate stage found in an ecosystem advancing towards its climax community.
- Climax community - A community that has reached a stable stage of ecological succession

Pioneer Community
Serial Stage –I
Serial Stage –II
Serial Stage –III
Serial Stage – IV
Climax stage



Ecological Succession:

- **Slow but continuous replacement of the ecosystem** over a period of time in any particular area is called **ecological succession**.

- Different stages of succession are called **seral stages** and all **these seral stages constitute a sere.**

- First community- **Pioneer community**

- Last community- **Climax Community**

Types of Succession

➢**Primary succession:** When an **unexposed area gets occupied by a living community** for the first time.

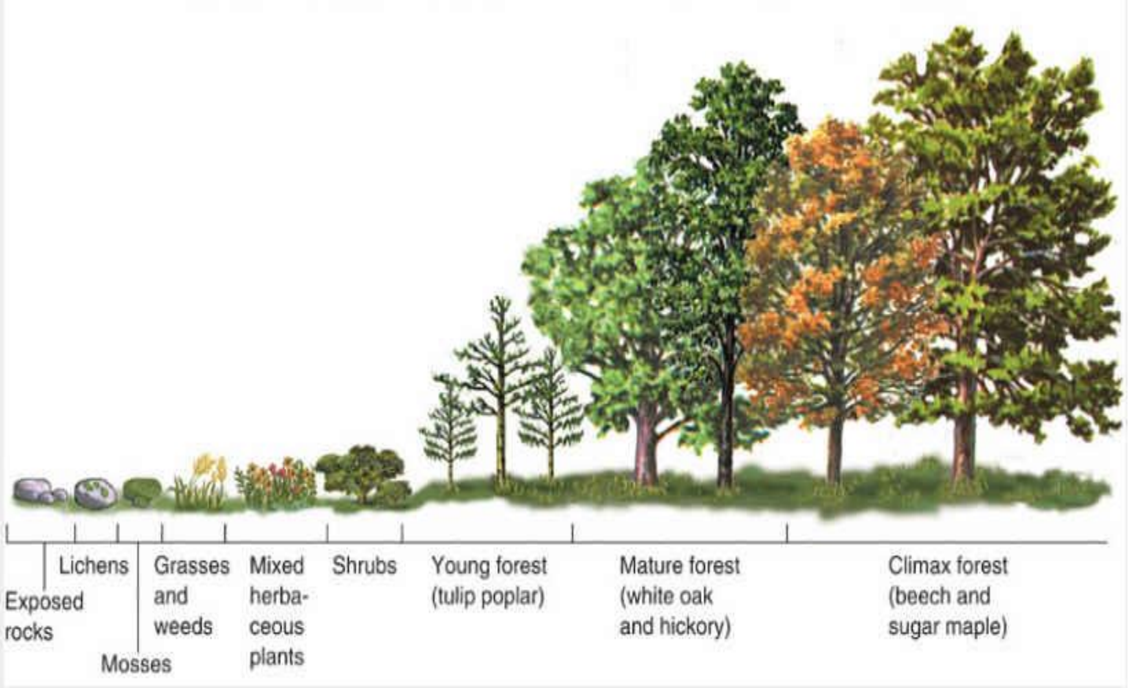


Fig. 9: Primary succession on a baren land (Lithosere or Xerosere)

➢**Secondary succession:** When **a new biotic community replaces** an already **existing biotic** community. For example, farm garden.

➢**Climax Community:** The community that is **formed at the end of succession**.

BIODIVERSITY HOT SPOT

- A **biodiversity hotspot** is a bio-geographic region with a significant reservoir of biodiversity that is under threat from humans.
- The concept of biodiversity hotspots was originated by **Norman Myers** in two articles in "*The Environmentalist*" (1988 & 1990), revised after thorough analysis by Myers and others in "**Hotspots**:
- Earth's Biologically Richest and Most Endangered Terrestrial Eco-regions".
- Major criteria for designating an area as hotspot are:
  - richness in endemic species, and
  - impact by human activities.

Criteria for Hotspots

- To qualify as a biodiversity hotspot on Myers (2000) edition of the hotspot-map, a region must meet **two strict criteria**:

1. It must contain at least 0.5% or 1,500 species of vascular plants as endemics

2. It has to have lost at least 70% of its primary vegetation.

- Around the world, at least 25 areas qualify under this definition, with nine others possible candidates.

- These sites support nearly 60% of the world's plant, bird, mammal, reptile, and amphibian species, with a very high share of endemic species.

Hotspots in India

- India is part of two **hotspots**

  1. ***Indo-Burma (earlier Eastern Himalayas)***

  2. ***Western Ghats***

- Of late, conservationists named **9** new **'Biodiversity Hotspots'**, making the total to **34**, which also include the ***Himalayas*** .

End of Lecture – 1: Basics of Ecology

Next Class

Lec 2: Biodiversity

Lecture-2: ESI101: B Tech – II Semester

Biodiversity: Importance & Assessment

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What is Biodiversity?

Biological diversity is the variety and variability among living organisms and the ecological complexes in which they occur.

Biodiversity is the variety of life, including variation among genes, species and functional traits.

It is often measured as:

1. Richness is a measure of the number of unique life forms;
2. Evenness is a measure of the equitability among life forms; and
3. Heterogeneity is the dissimilarity among life forms.

Year 1992

In 1992, India was one of 188 countries that ratified the Convention on Biological Diversity (CBD) at the Rio Earth Summit entered into force on 29 December 1993.

The convention recognizes that ecosystems, species and genes are used for the benefit of humans.

The official definition of Biodiversity

"The variability among living organisms from all sources, including, *inter alia, terrestrial,* marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Convention on Biological Diversity, 1992).

Biodiversity is the totality of

- **Genetic diversity**
- **Species Diversity**
- **Ecosystem Diversity**

National Conservation Strategy Act (NCS Act, 1992)

The National Conservation Strategy Act (NSC Act , 1992) & Policy Statement on Environment of Development *(1992)* adopted by the GOl in June 1992 came out on the eve of the Earth Summit held in Rio de Janerio, Brazil from 3-12th June 1992, where155 Nations sign the convention.

The Indian Challenge

Article 6: Integrate, as far as possible and an appropriate, the conservation and sustainable use of biological diversity.

Article 14: "Introduce appropriate procedures requiring EIA of its proposed projects that are likely to have significant adverse effects on biological diversity with a view to avoiding or minimizing such effect."

Immediate effect was to incorporate bio-diversity concerns in the existing EIA procedure.

Objectives

- The Biological Diversity Act 2002 is a law meant to achieve three main objectives: f

1. the conservation of biodiversity; f
2. the sustainable use of biological resources; f
3. equity in sharing benefits from such use of resources.

The Structure of Biodiversity Act – 2002

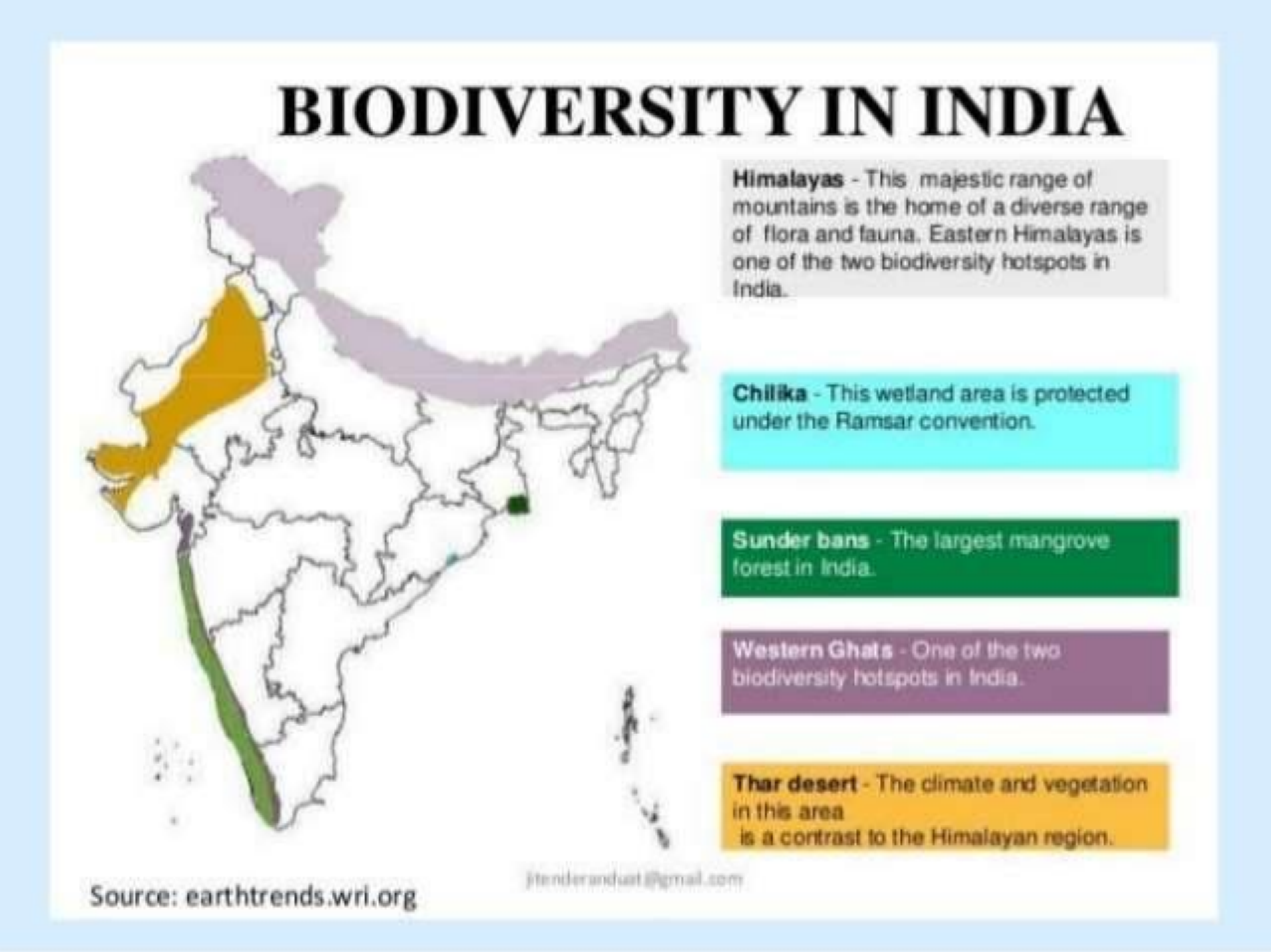
1. **National Biodiversity Authority (NBA)**
2. **State Biodiversity Boards (SBB)**
3. **Biodiversity Management Committees (BMC)s**

❖ Any offence under this Act is non-bailable and cognizable

- **Mega-biodiversity Nation**
- **Vavilov Centre**
- **Indian biodiversity – known for its Endemism**

India is a highly biodiverse country, holding over <u>45,000 species </u>of plants in only 2.4% of the world's land area.

Over 12% of wild mammal species are threatened with extinction in the country.



Measurement of Biodiversity

Measurement of Biodiversity

- The simplest measurement of species diversity is to count the number of species in an area, i.e, known as species richness.

- First and oldest concept of species diversity is species richness (d) - relates between
  - Number of species (S) and
  - Number of individuals of each species (N).

- Following species richness indices are used:

1. Margalef's index (D_{Mg}): $\frac{S-1}{\ln N}$,

2.Menhinik index (D_{Mn}) = $\frac{S}{\sqrt{N}}$

Where;

S = Nos of Species,

N = Nos of Individuals

Species Richness Index

Drawback: does not take species abundance into account.

EXAMPLE 1: Imagine two hypothetical communities A & B, both with 100 individuals.

	Number of individuals of species 1	Number of individuals of species 2
Community A (N = 100) S=2	TeaK = 99	Gulmohar = 1
Community B (N =100) S=2	Teak = 50	Gulmohar = 50

✓Both communities A & B are equal in species richness, but B has a higher equitability or evenness.

✓To measure diversity, one must incorporate both abundance & species richness in measures of species diversity

Calculation Biodiversity: By Using Species Richness Index (d)

- By applying richness indices, both communities A and B show equal in species richness, but B has a higher equitability or evenness of the species richness:

  Margalef's index (D_{Mg}): (S - 1)/ln N = (2 - 1)/ ln 100 = 1 /0.605 = 0.217 (d);

  Menhinik index (D_{Mn}) = S/(√N) = 2 / √100 = 2/10 = 0.2;

  ➢ Conclusion: Both community have same species diversity (Species richness).

  ➢ But community B is best and most desiable.

- Therefore, during the measurement of species diversity, both abundance (i.e., evenness of distribution of species) and species richness has to be considered.

Types of Biodiversity indices

There are many indices, but we can divide them into two broad categories:

1.DOMINANCE INDICES – Dominance indices are weighted towards the abundance of the commonest species.

(a) Berger & Parker index (1970) and
(b) Simpson's index of dominance (Simpson, 1949);

1. ***INFORMATION- STATISTIC INDICES*** :
   a) Shannon index (1949) and

Berger–Parker Index (D_{BP}): *DOMINANCE INDICES*

(D_{BP}) = (ni_{max})/ N total

- ni_{max} = total number of individuals in the most common species;
- N = total number of individuals in the community.

Example 2: Date sets for Berger-parker index

Species	Com 1	Com 2
a	10 (ni)	5
b	10	5
c	10	5
d	10	5
e	10	5
f	10	5
g	10	5
h	10	5
i	10	5
j	10	55 (ni)
Total number of individuals	N=100	N=100
Total number of species	10	10

D_{BP} for Com1= 10/100 = 0.1
D_{BP} Com2 = 55/100 = 0.55

To express greater diversity with a numerically greater value, we usually use a reciprocal form of the index.

D_{BP} = 1/D, so that more diverse community actually have a higher index of diversity. In this case,

For Com1, D_{BP} **= 1/0.1 = 10 (Higher diversity)**
Com2 **D_{BP} = 1/0.55 = 1.82 (lower diversity)**

A huge advantage of the Berger-Parker index over the others is that it is very easy to compute.

Simpson’s index (Ds)
(Simpson, 1949) - a dominant index: 0 and 1

For infinite sample the Simpson’s index is:

$Ds = 1 - C$,

Where, $C = \sum (ni / N_{total})^2$

- Where;

$pi = ni/N$;

ni = total number of individuals in each species;

N= total number of individuals in all species;

S = total number of species.

<u>Example - 4</u>: Calculate Simpson's diversity index for following plant community of an area

SL	Name of Species	No on Individual	$pi = ni/N$
1	Mango	3	=3/65
2	Jamun	5	
3	Guava	16	
4	Sissoo	12	
5	Teak	8	
6	Sal	2	
7	Mahua	7	
8	Amaltas	3	
9	Mahagony	6	
10	Rain tree	3	
Total Individuals (N)		= 65	

Solution of Example 2:

$$D_s = 1 - \sum \left(\frac{n}{N}\right)^2$$

D_s = Diversity Index

n = Number of individuals for each species

N = Total number of all individuals

$$\left(\frac{3}{65}\right)^2 + \left(\frac{5}{65}\right)^2 + \left(\frac{16}{65}\right)^2 + \left(\frac{12}{65}\right)^2 + \left(\frac{8}{65}\right)^2 + \left(\frac{2}{65}\right)^2 + \left(\frac{7}{65}\right)^2 + \left(\frac{3}{65}\right)^2 + \left(\frac{6}{65}\right)^2 + \left(\frac{3}{65}\right)^2 =$$

$$.002 + .006 + .061 + .034 + .015 + .0009 + .012 + .002 + .009 + .002 =$$

$$.144$$

$$D_s = 1 - .144 = .856$$

Shannon index (H)

1. The widely used Shannon index (H) is one of the best indices which is reasonable independent of sample size and also normally distributed (Odum 1971).

2. The greater the value of H, the higher is the diversity.

3. The value of H can be more than 1.

4. Higher diversity value occurs when the number of species and the evenness component are large (**low dominance**).

Application of Shannon index (H) in Example 1: (Slide no 9)

	Number of individuals of Com 1	Number of individuals of Com 2
Community A	99	1
Community B	50	50

$H = - \sum p_i \ln p_i$

Where,

pi = ni/N and

'ln' denotes the natural logarithms.

- For com – A: [0.99 (ln 0.99) + 0.01 (ln 0.01)] = 0.056 (Ans)
- For com – B: [0.5 (ln 0.5) + 0.5 (ln 0.5)] = 0.69 (Ans)

- The second plant community (B) is much more diverse than the first community. The higher the value of H, the greater the diversity.

Example 4: Calculate Shannon index of Diversity (H)

$H = - \sum p_i \ln p_i$ Where, pi = ni/N and & 'ln' denotes the natural logarithms.

SL	Name of Species	No on Individual	pi = ni/N
1	Mango	3	=3/65
2	Jamun	5	
3	Guava	16	
4	Sissoo	12	
5	Teak	8	
6	Sal	2	
7	Mahua	7	
8	Amaltas	3	
9	Mahogany	6	
10	Rain tree	3	
Total Individuals (N)		= 65	

Solution of Example 4: Calculation of Shannon index (H)

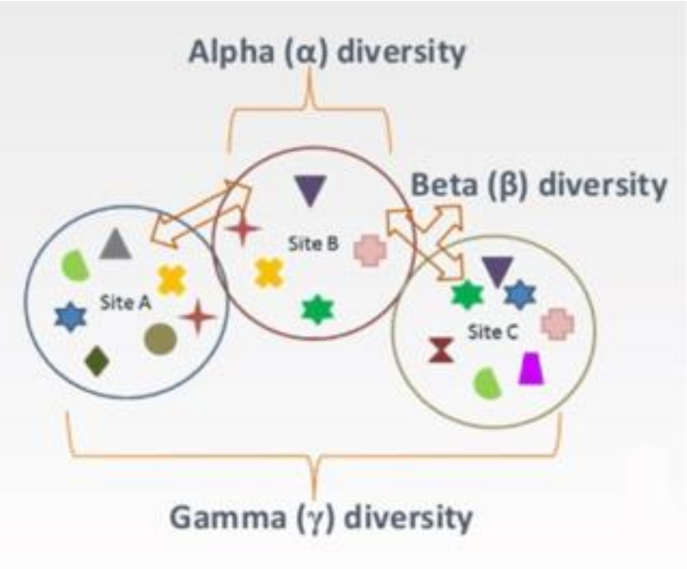
Name of species	Nos of individuals (ni)	pi = (ni/N)	ln pi	H = - ∑ pi * ln pi
Mango	3	(3/65) = .0461	-3.0757	-0.1418
Jamun	5	(5/65) =		
Guava	16	(16/65) =		
Sissoo	12	(12/65) =		
Teak	8	(8/65) =		
Sal	2	(2/65) =		
Mahua	7	(2/65) =		
Amaltas	3	(2/65) =		
Mehogany	6	(2/65) =		
Rain Tree	3	(3/65) =		
	Total = 65			H = ??

✓Values of Shannon index for real communities are often found to fall between 1.5 and 3.5.

Alpha (α), beta (β), gamma (γ) biodiversity

- Alpha -Diversity: Called intra-biotopic diversity or diversity within one components.

1. It measures the number of species in single community.
2. Diversity within a particular area, community or ecosystem is known α-diversity.
3. i.e., Number of taxa (species usually) present in an ecosystem is a measure of α- diversity.



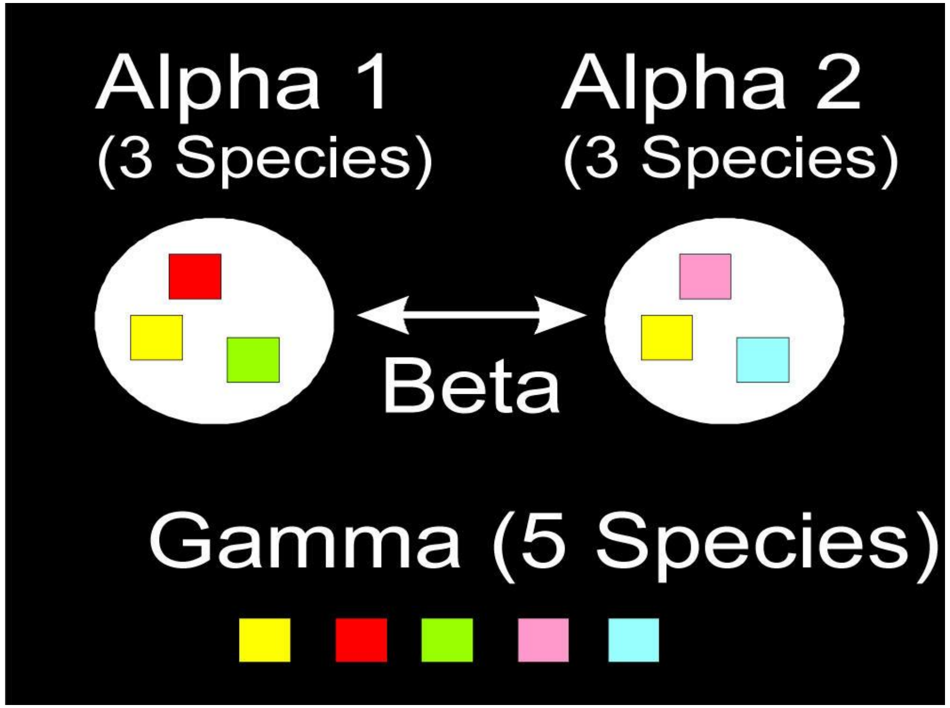
Beta (β)Diversity:

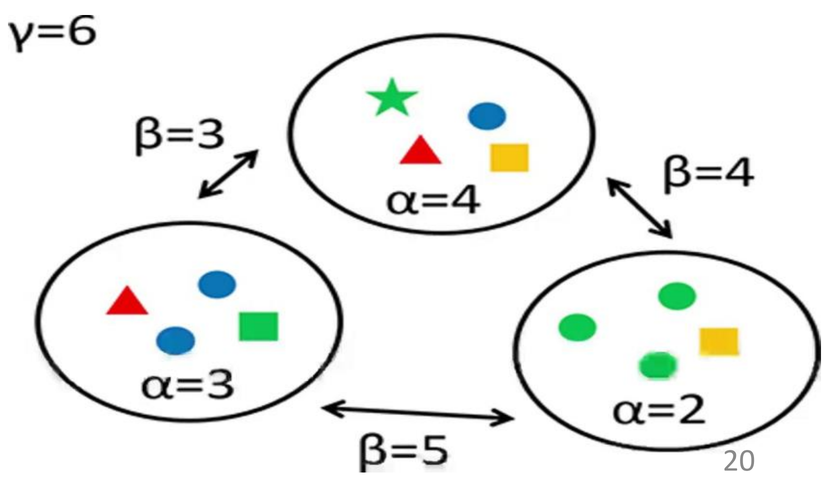
- Beta Diversity: Species diversity between two ecosystems is β-diversity.

- **It compare the differences of population between two adjacent biotopes, that is, diversity between two habitats,**

1. For example, change in species composition along the environmental gradients.

2. Comparing the number of taxa that are unique to each of the ecosystem is β -diversity



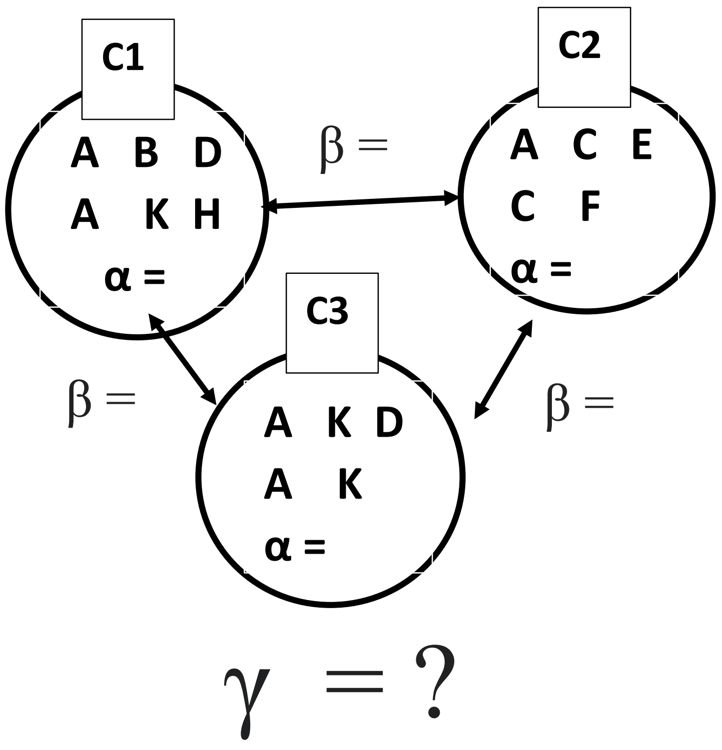


Example - 5:

Three Circular box represent 3 communities (C1, C2 and C3).

Alphabets (A, B and so on) represents specific species.

Calculate **α**, β and γ diversity



END of Lecture 2

on

Biodiversity, & Their Assessment

(Hints: Practice all Examples)

Next Class

Lec 3: Water Pollution

End of Lecture – 2: Basics of Ecology

Next Class

Lec 2: Biodiversity

Lecture-3

Fresh Water Resources and Water Pollution

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WATER RESOURCES AND HYDROLOGOICAL CYCLE

- Water covers approximately **three-fourths** of the surface of the earth.
- Over **98 %** of the total water supply is contained in the **oceans** and **other saline bodies** of water.
- Of the **remaining 2%** freshwater, **87% is** tied up in **ice caps and glaciers**. Another **12% is groundwater**.
- **Humans depend** upon the **remaining 1%** of the freshwater present in lakes and rivers.

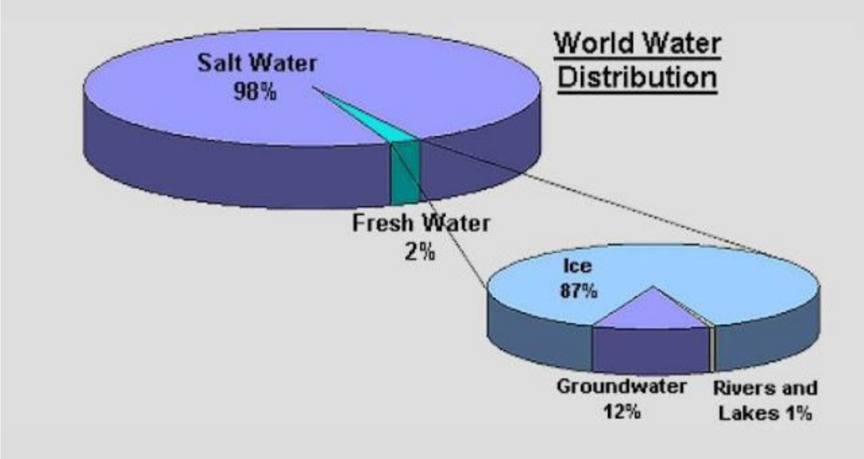


Fig. 1: World water distribution

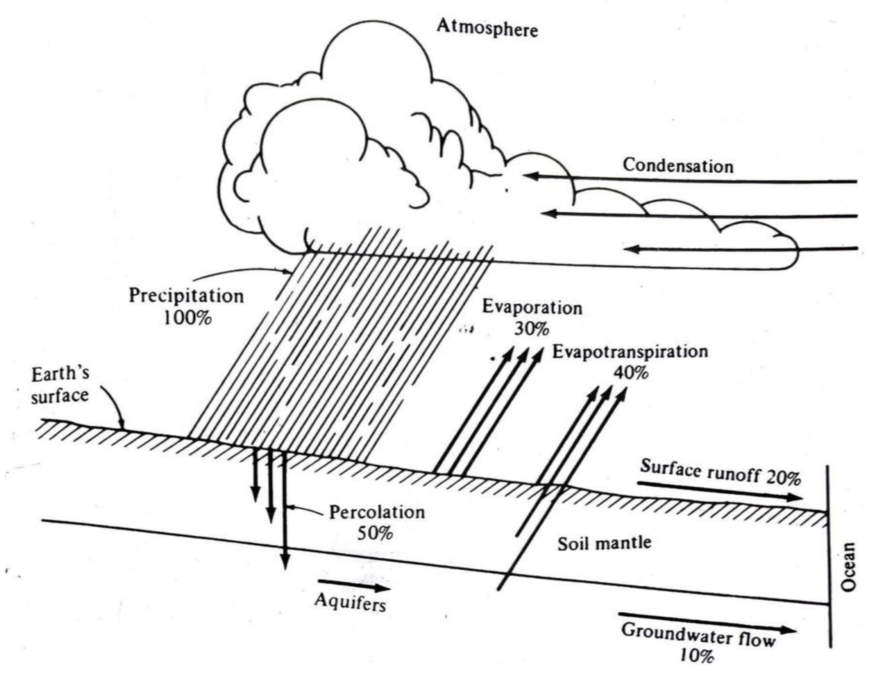


Fig. 2: The hydrological cycle

Table 1: Classes of water

Designated best use	Class	Criteria
Drinking water source without conventional treatment but after disinfections	A	Total coliform organisms MPN/100ml shall be 50 or less.
		pH between 6.5 and 8.5
		Dissolved oxygen 6 mg/l or more
		Biochemical oxygen demand 2 mg/l or Less
Outdoor bathing (organized)	B	Total coliform organisms MPN/100ml shall be 500 or less
		pH between 6.5 and 8.5
		Dissolved oxygen 5 mg/l or more
		Biochemical oxygen demand 3 mg/l or Less
Drinking water source with conventional treatment followed by disinfection	C	Total coliform organisms MPN/ 100ml shall be 5000 or less
		pH between 6 and 9
		Dissolved oxygen 4 mg/l or more
		Biochemical oxygen demand 3 mg/l or less
Propagation of wild life, fisheries	D	pH between 6.5 and 8.5
		Dissolved oxygen 4 mg/l or more
		Free ammonia (as N) 1.2 mg/l or less
Irrigation, industrial cooling, controlled waste disposal	E	pH between 6.0 and 8.5
		Electrical conductivity less than 2250 micro mhos/cm
		Sodium absorption ratio less than 26
		Boron less than 2mg/l

WATER SUPPLY SOURCES

1. **Surface water sources:** Natural **ponds, lakes, streams, rivers**, impounding reservoirs (surface water storage).

2. **Groundwater sources:** Infiltration **galleries**, Infiltration **wells**, **Hand pumps**, Deep tube Wells, Wells.

Factors governing the selection of a particular source of water:

- **Quantity** of available water
- **Quality** of available water
- **Distance** of the source of supply

WATER POLLUTION

The **presence of impurities** in such quantity and of such nature as **to impair the use of the water for a stated purpose**.

Water pollutants

- **Pathogens**
- **Oxygen-demanding waste**
- **Nutrients**
- **Salts**
- **Heavy metals**

Table 2: Typical pathogens and associated diseases

Organism	Disease
Bacteria	
Salmonella paratyphi (A, B, C)	Paratyphoid (enteric fever)
Salmonella typhi	**Typhoid fever, enteric fever**
Shigella (S. flexneri, S. sonnei, S. dysenteriae, S. boydii)	Shigellosis (bacillary dysentery)
Vibrio comma (*Vibrio cholerae)*	**Cholera** (Asiatic, Indian, El Tor)
Viruses	
Enteric cytopathogenic human orphan (ECHO) (ECHO)	Aseptic meningitis, epidemic exanthem. infantile diarrhea
Poliomyelitis (3 types)	Acute anterior poliomyelitis, infantile paralysis
Unknown viruses	Infectious hepatitis
Protozoa	
Entamoeba histolytica	Amebiasis (amebic dysentery, amebic enteritis, amebic colitis)
Giardia lamblia	Giardiasis (Giardia enteritis, lambliasis)
Helminths (parasitic worms)	
Dracunculus medinensis	Dracontiasis (dracunculiasis; dracunculosis; medina; serpent, dragon, or guinea-worm infection)
Echinococcus	Echinococcosis (hydatidosis; granulosus; dog tapeworm)
Schistosoma (S. mansoni, S. japonicum, S. haematobium)	Schistosomiasis (bilharziasis or "Bill Harris" or "blood fluke" disease)

Table 3: Physical parameters of water

Parameters	Sources	Impacts	Measurements
Colour	**Organic debris** such as leaves, weeds, or wood. **Industrial wastes** from textile, pulp and paper production, food processing, chemical production, and slaughterhouse operations.	Coloured water is not aesthetically acceptable to the general public. It affects the acceptability of water for both domestic and industrial use.	Tintometer
Taste and Odour	**Inorganic solids:** Clay, silt or other soil constituents. **Organic solids:** Plant fibers and biological solids (algal cells, bacteria, etc.).	Aesthetically displeasing. Provides adsorption sites (surfaces) for chemical and biological agents. Biological degradation of organic solids may produce objectionable by-products.	Gravimetric tests involving the mass of residues. Expressed as milligrams per liter (mg/L) on a dry-mass-of-solids basis.
Turbidity	**Erosion of colloidal materials** such as clay, silt and metal oxides from the soil. **Domestic and industrial wastewater.**	Opaqueness or 'milky' coloration. Turbidity-producing colloidal materials provide adsorption sites for chemicals and harmful organisms. It may interfere with light penetration and photosynthetic reactions in streams and lakes.	Jackson turbidimeter; Nephelometric turbidity meter
Temperature	Hot water discharge from many industries in rivers and streams.	Affect the reaction rates and solubility levels of chemicals in water bodies. Affects aquatic life dramatically by sudden elevation in temperature.	Measure using Celsius or Fahrenheit scales.

Table 4: Chemical parameters of water

Parameters	Sources	Impacts	Measurements
pH	Presence of chemicals, minerals, and pollutants in water.	High pH of water can indicate pollutants or unwanted chemicals present in water.	pH meter and pH indicator strips.
Electrical Conductivity	Presence of ions such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^{+}), Bicarbonate (HCO_3^{-}), Sulphate (SO_4^{2-}), and Chloride (Cl^{-}), etc.	The high amount of salts and heavy metals are harmful to aquatic life and to humans also.	Electrical conductivity meter. Expressed in units of mhos per centimeter (mho/cm).
Acidity	Presence of uncombined carbon dioxide, mineral acids and salts of strong acids and weak bases.	Corrosion in public water supply systems.	Chemical titration. Expressed as milligrams per liter of $CaCO_3$.
Alkalinity	Presence of carbonate bicarbonate, hydroxide, phosphates, sulfide, and ammonia.	Bitter taste to water. Precipitates may damage pipes and other appurtenances.	Chemical titration. Expressed as milligrams per liter of $CaCO_3$.
Hardness	Salts of calcium, magnesium, iron, manganese, and aluminum.	Hardness cations form a precipitate that may stain the cloths and utensils. Use of hard water may result in rough, uncomfortable skin.	Spectrophotometric techniques or chemical titration.
Metals	Natural, industrial, or agricultural sources.	Impart a Colour, bitter taste, and odour in water. Carcinogenic causes liver, kidney, and skin cancer.	Atomic Absorption spectrometry (AAS). Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). ICP- Mass Spectrometry (ICP-MS).

CHEMICAL WATER-QUALITY PARAMETERS

pH

Example: Find the pH of a solution of 0.002 M of HCl.

Solution: The equation for pH is -log $[H^+]$

$$[H] = 2.0 \times 10^{-3}\ M$$

$$pH = -\log [2.0 \times 10^{-3}]$$

$$= \mathbf{2.70}$$

DISSOLVED OXYGEN

- Dissolved oxygen (DO) is the **amount of oxygen that is present in water**.
- Water bodies **receive oxygen** from the **atmosphere** and **aquatic plants**.
- **DO analysis is a key test in water pollution** and **waste treatment process control.**

BIOCHEMICAL OXYGEN DEMAND (BOD)

- Defined as the **amount of oxygen required** by microorganisms to stabilize decomposable organic matter at a particular time and temperature.
- The **BOD of a diluted sample** is calculated by

$$\boldsymbol{BOD_5 = \frac{(DO_i - DO_f)}{P}}$$

Where **DO_i and DO_f are the initial and final dissolved-oxygen** concentrations (mg/L) and **P is the dilution factor** of the sample in the 300-mL bottle.

Example 1: A wastewater sample of 30 mL is diluted up to 300 mL with distilled water. The initial DO of the diluted sample was 7.2 mg/L and the same after 5 day incubation at 20 ^{0}C was 2.2 mg/L. Find the BOD after 5 days?

Solution: Initial Dissolved Oxygen (DO_i) = 7.2 mg/L

Final Dissolved Oxygen (DO_f)= 2.2 mg/L

Dilution Factor (P) = (Vol. of undiluted sample)/(Vol. of diluted sample) =30/300 = 0.1

$$BOD_5 = \frac{(DO_i - DO_f)}{P} = (7.2 - 2.2)/0.1 = $$ **50 mg/L (Ans)**

Mathematical Formulation of BOD

The **rate at which organics are utilized by microorganisms is assumed to be a first-order reaction.**

Mathematically, this can be expressed as follows:

$$\frac{dL_t}{dt} = -kL_t$$

Taking integrals on both sides

$$\frac{dL_t}{L_t} = -k\,dt$$

$$\int_{L_0}^{Lt} \frac{dL_t}{L_t} = -k \int_0^t dt$$

$$ln\frac{L_t}{L_0} = -kt$$

$$L_t = L_0 e^{-kt}$$

- $\mathbf{L_t}$ is the **oxygen equivalent** of the organics **at time t** (milligrams per liter).
- k is a reaction constant (d^{-1}).
- The term $\mathbf{L_o}$ represents the **total oxygen equivalent** of the organics at time 0.

If L_o is the oxygen equivalent of the total mass of organics, then the **difference between the value Lo and L_t is the oxygen equivalent consumed, or the BOD exerted**.

Mathematically,

$$y_t = L_0 - L_t$$
$$y_t = L_0 - L_0 e^{-kt}$$
$$y_t = L_0(1 - e^{-kt})$$

- y_t represents the BOD_t exerted.

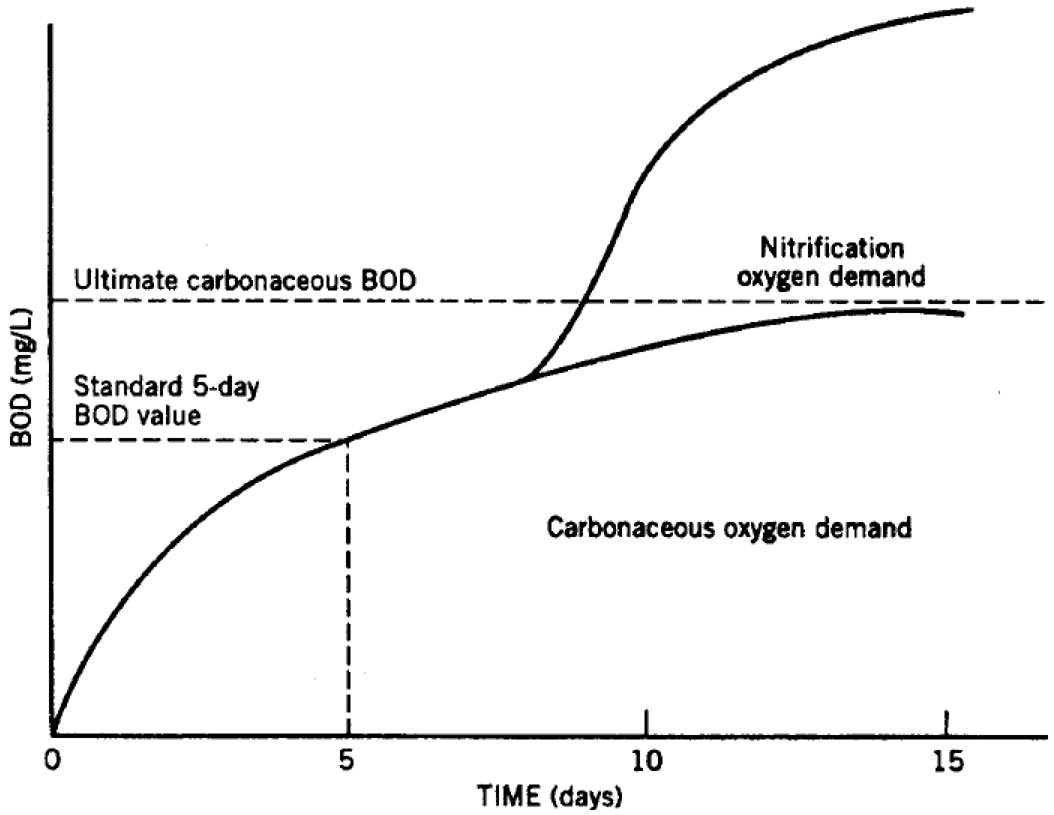


Figure 7.4 Carbonaceous and autotrophic BOD. From Hammer (1986). (Courtesy of John Wiley.)

The value of **k determines the speed of the BOD reaction** without influencing the magnitude of the ultimate BOD.

The change in k can be approximated by the van't Hoff-Arrhenius model:

$$\boldsymbol{k_T = k_{20}\theta^{T-20^\circ}}$$

Where, $\mathbf{K_T}$ **is rate constant at any temperature** (d^{-1}), K_{20} is rate constant at temperature 20°C (d^{-1}), and **θ is temperature coefficient**. A value of **1.047 for θ** is often used.

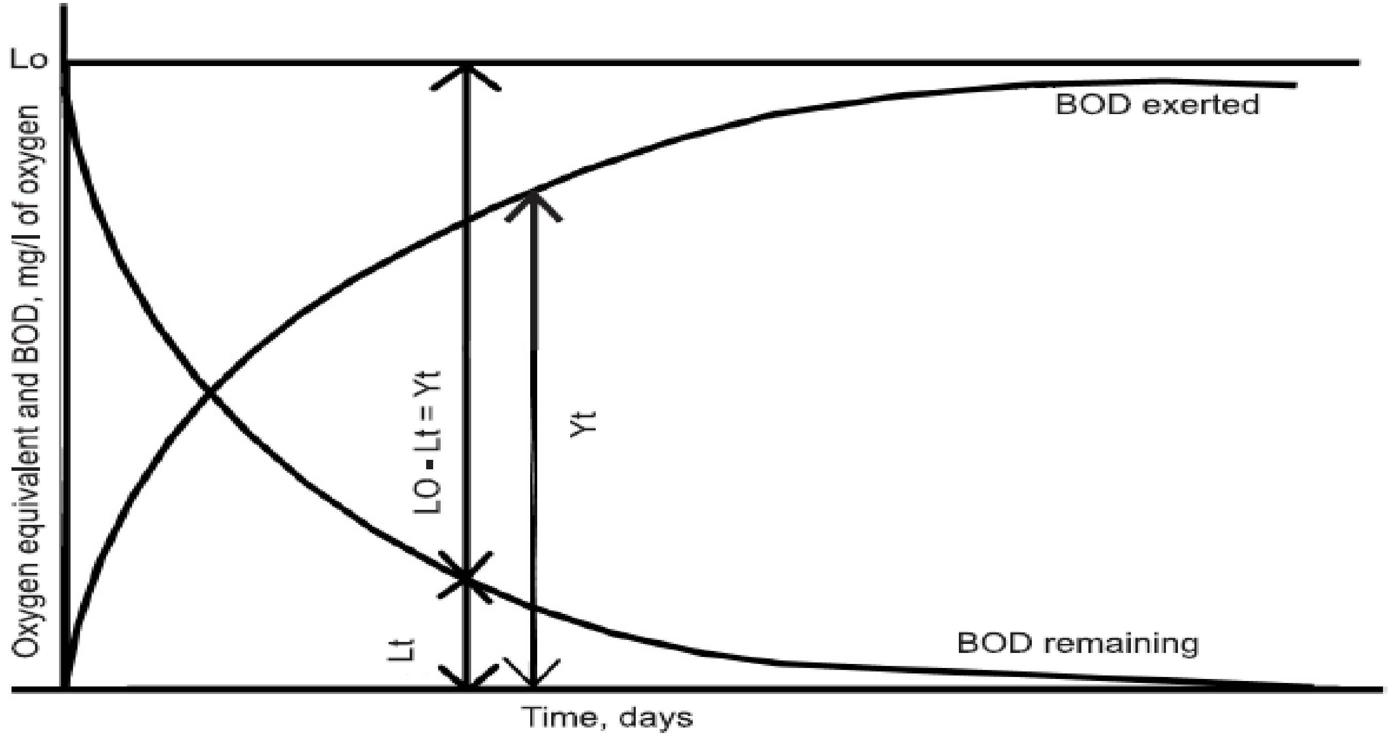


Fig. 3: BOD and oxygen-equivalent relationships

Example 2: The BOD_5 of a wastewater is determined to be 150 mg/L at 20 °C. The k value is known to be 0.23 per day at 20 °C. What would the BOD_8 be if the test was run at 15 °C?

Solution:

Given, BOD_5 (y_t) = 150 mg/L, k =0.23 per day, T= 15°C, e = 2.718

1. Determine the ultimate BOD.

$y_t = L_0(1 - e^{-kt})$; *yt = BOD of any day; Lo = Ultimate BOD*

$$L_0 = \frac{y_t}{1-e^{-kt}} = \frac{150}{1-e^{-0.23 \times 5}} = 220 \text{ mg/L}$$

Lo = 220 mg/L (ultimate BOD

2. The k value for 15°C.

$$k_T = k_{20}\theta^{T-20°}$$

K_{15} = 0.23 (1.047^{15-20}) = **0.18/day**

KT = Correction of rate constant for a particular temperature in ^{0}C.

3. Calculate BOD_8 (y_8)

$y_8 = L_0(1 - e^{-kt})$= 220 (1- $e^{-0.18 \times 8}$) = **168 mg/L (Ans)**

Practice examples on BOD

1. If BOD5 of a wastewater sample measured at 20 ^{0}C is 250 mg/L and reaction rate constant (k to base e) is 0.35/day, compute the ultimate BOD (BOD_L) and the 3-days BOD. *(Ans. BOD_L = 302.6 mg/L & L_3 = 106 mg/L).*

2. If BOD_5 of a sample measured at 20 ^{0}C is 250 mg/L, determine the 3-days BOD at 27 ^{0}C. Assume a reaction rate constant (k to the base e) = 0.23/day at 20 ^{0}C; θ = 1.056. (Ans: L3 = 234 mg/L).

3. Determine ultimate BOD for a water sample whose 5-days , 20 ^{0}C BOD is 200 mg/L. Assume reaction rate constant (k to base e) is 0.35/day. (Ans: Ultimate BOD, BOD_L = 293 mg/L).

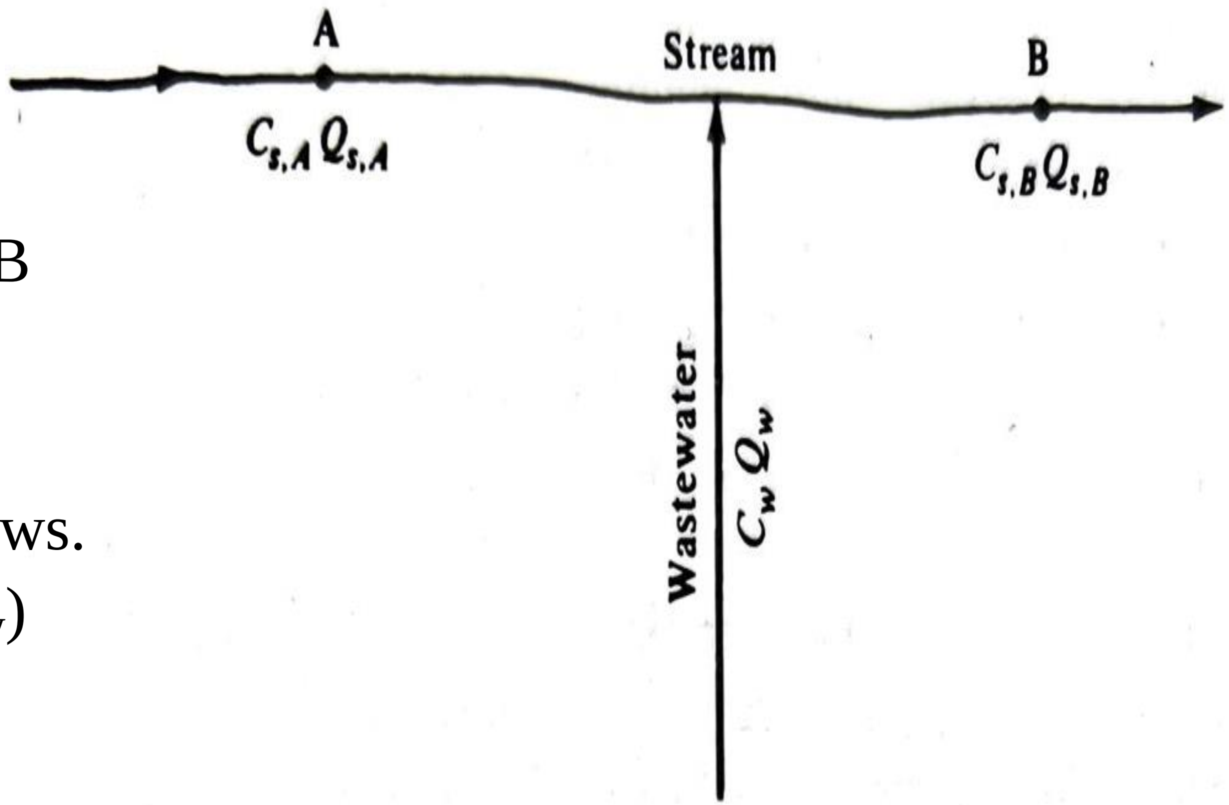
Table 5: Drinking Water Quality Standards as per BIS [IS: 10500, 2012, 1st amendment (2015)]

S. No.	Name of the Parameter	Acceptable Limit	Permissible Limit in the Absence of Alternate Source
Physical Parameters			
1.	Colour, Hazen units, *Max*	5	15
2.	Odour	Agreeable	Agreeable
3.	*p*H value	6.5-8.5	No relaxation
4.	Taste	Agreeable	Agreeable
5.	Turbidity, NTU, *Max*	1	5
6.	Total dissolved solids, mg/l,	500	2000
General Parameters Concerning Substances Undesirable in Excessive Amounts			
7.	Aluminium (as Al), mg/l, *Max*	0.03	0.2
8.	Ammonia (as total ammonia-N), mg/l *Max*	0.5	No relaxation
9.	Anionic detergents (as MBAS= M**ethylene Blue Active Substances Assay**) mg/l *Max*	0.2	1.0
10.	Barium (as Ba), mg/l, *Max*	0.7	No relaxation
11.	Boron (as B), mg/l, *Max*	0.5	1.0
12.	Calcium (as Ca), mg/l, *Max*	75	200
13.	Chloramines (as Cl_2), mg/l, *Max*	4.0	No relaxation
14.	Chloride (as Cl), mg/l, *Max*	250	1 000
15.	Copper (as Cu), mg/l, *Max*	0.05	1.5

Contd.

16.	Fluoride (as F) mg/l, *Max*	1.0	1.5
17.	Free residual chlorine, mg/l, *Min*	0.2	1
18.	Iron (as Fe), mg/l, *Max*	1.0	No relaxation
19.	Magnesium (as Mg), mg/l, *Max*	30	100
20.	Manganese (as Mn), mg/l, *Max*	0.1	0.3
21.	Mineral oil, mg/l, *Max*	0.5	No relaxation
22.	Nitrate (as NO_3), mg/l, *Max*	45	No relaxation
23.	Phenolic compounds (as C_6H_5OH), mg/l, *Max*	0.001	0.002
24.	Selenium (as Se), mg/l, *Max*	0.01	No relaxation
25.	Silver (as Ag), mg/l, *Max*	0.1	No relaxation
26.	Sulphate (as SO_4) mg/l, *Max*	200	400
27.	Sulphide (as H_2S), mg/l, *Max*	0.05	No relaxation
28.	Total alkalinity as calcium carbonate, mg/l, *Max*	200	600
29.	Total hardness (as $CaCO_3$), mg/l, *Max*	200	600
30.	Zinc (as Zn), mg/l, *Max*	5	15
Parameters Concerning Toxic Substances			
31.	Cadmium (as Cd), mg/l, *Max*	0.003	No relaxation
32.	Cyanide (as CN), mg/l, *Max*	0.05	No relaxation
33.	Lead (as Pb), mg/l, *Max*	0.01	No relaxation
34.	Mercury (as Hg), mg/l, *Max*	0.001	No relaxation
35.	Molybdenum (as Mo), mg/l, *Max*	0.07	No relaxation
36.	Nickel (as Ni), mg/l, *Max*	0.02	No relaxation
37.	Total arsenic (as As), mg/l, *Max*	0.01	No relaxation
38.	Total chromium (as Cr), mg/l, *Max*	0.05	No relaxation

Example 3 : A treated wastewater enters a stream as shown in the Fig. The concentration of Na in the stream at point A is 10 mg/L and the flow rate is 20 m^3/s. The concentration of Na in the wastewater stream is 250 mg/L and the flow rate is 1.5 m^3/s. Determine the concentration of sodium at point B assuming that complete mixing has occurred.



Solution: Mass balance between points A and B

Mass in = Mass out

$C_{S,B} * Q_{S,B} = C_{S,A} Q_{S,A} + C_W Q_W$

Since $Q_{S,B}$ is the sum of the other two flows.

$C_{S,B} = (C_{S,A} Q_{S,A} + C_W Q_W) / (Q_{S,A} + Q_W)$

$= (10 \times 20 + 250 \times 1.5) / (20 + 1.5)$

$=$ **26.7 mg/L (Ans)**

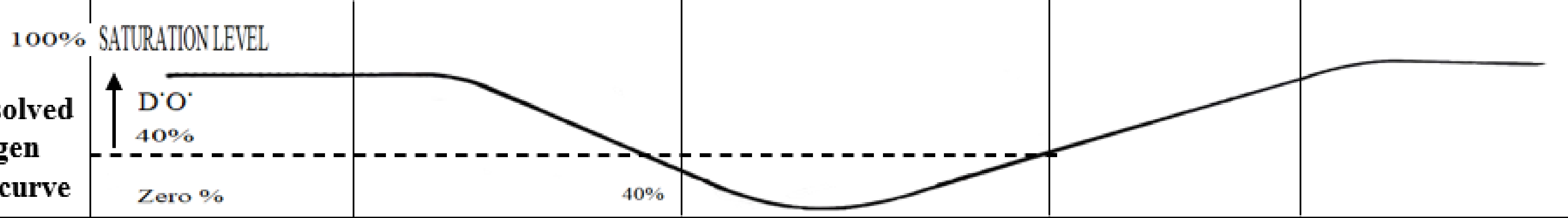
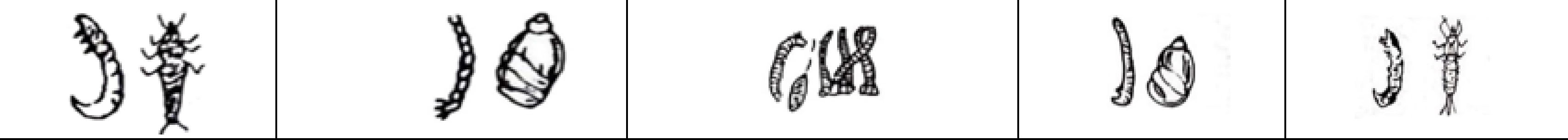
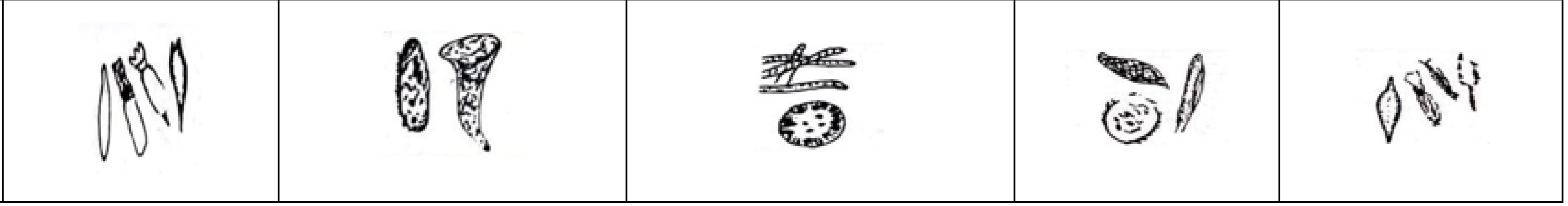
	Zones of Self-purification				
	Clear water	Zone of Degradation	Zone of Active Decomposition	Zone of Recovery	Zone of Clearer Water
Dissolved oxygen sag curve					
Physical indices	Clear water; No bottom sludge; No colour	Floating solids; Bottom sludge present, Colour getting turbid.	Darker and greyish colour; Evolution of gases like CH_4, CO_2, H_2S etc.; Lot of sludge coming to the surface forming an ugly scum layer at top.	Turbid with bottom sludge.	Clear water with no bottom sludge.
Fish presence	Ordinary fish like game, pan, food & forage, etc. present.	Tolerant fishes like carp, buffalo, gary, etc. present.	No fish present	Tolerant fish like carb buffalo, etc. are present.	Ordinary fish like game, pan, food, and forage, etc. present.
Bottom animals					
Algae & Protozoa etc. called Plankton					

Fig. 5: The physical, chemical, and biological indices and characteristics of each zone after waste discharge into the clean stream.

Process | **Chemicals added** | **Waste streams**

Aeration: Removes undesirable gases and/or oxidation of iron and manganese.

Softening: Removes calcium and/or magnesium Soda hardness; may be done in one or two stages.

Filtration: Removes residual $CaCO_3$ crystals and $Mg(OH)_2$, floc left over from softening; disinfectant may be added to prevent biological growth on filter medium.

Disinfection: Destroys pathogens; enough added to provide residual in the distribution system.

Storage: Provides contact time for disinfection and stores water for peak demand.

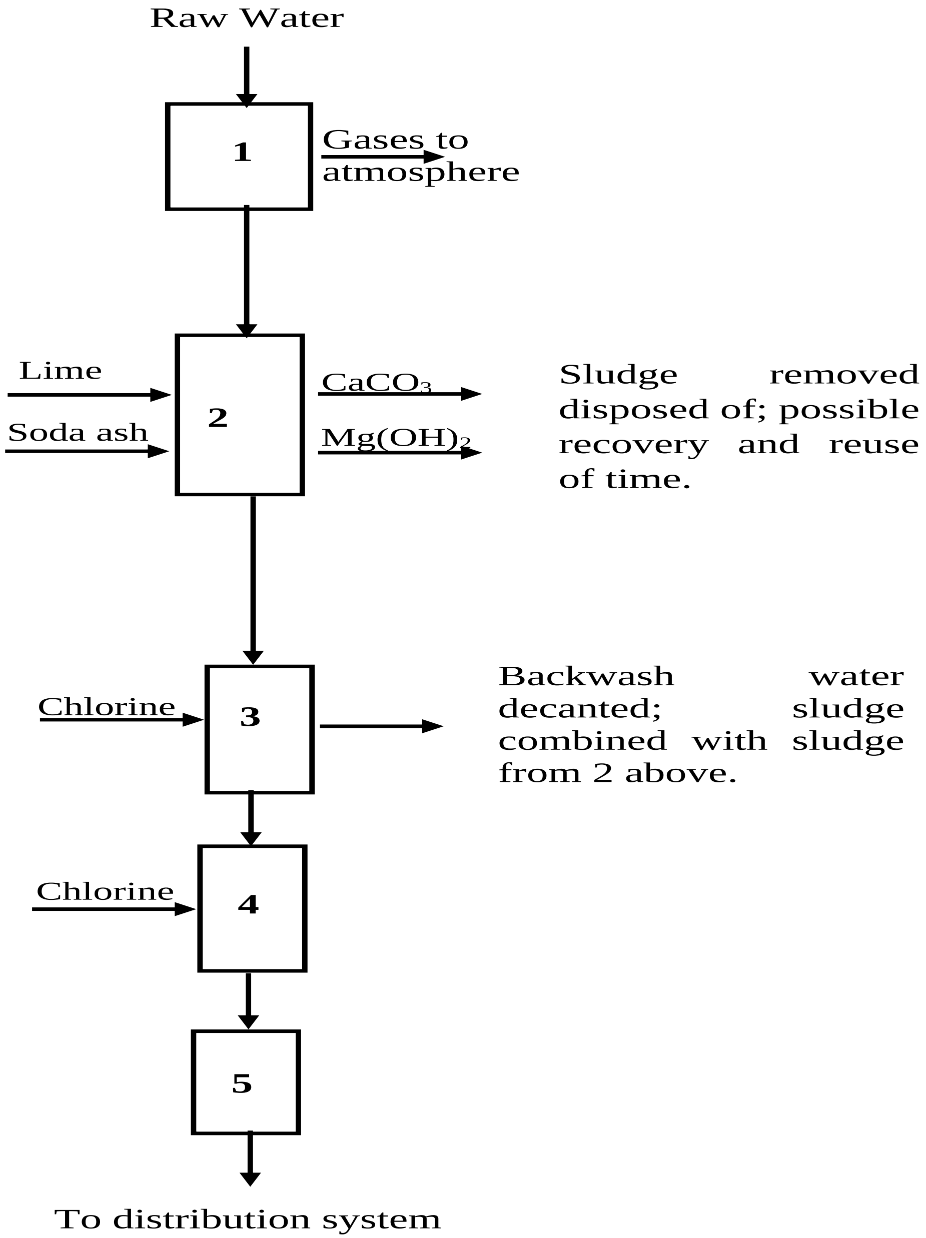


Fig. 7: Typical plant treating hard groundwater.

End of Lecture 3

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Water Pollution