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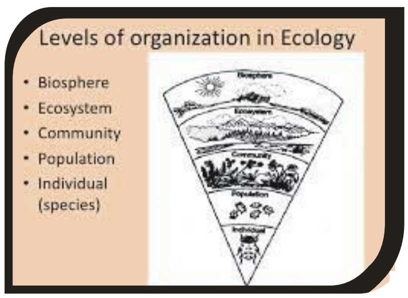
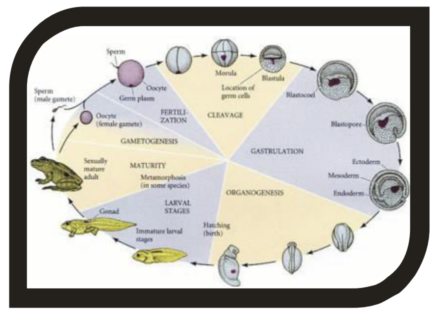
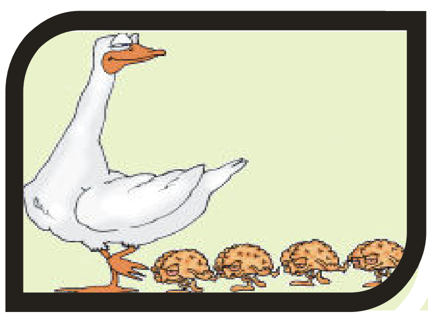
Vardhman Mahaveer Open University, Kota







Ecology, Ethology and Developmental Biology

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Vardhman Mahaveer Open University, Kota

Ecology, Ethology and Developmental Biology

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Preface

The present book entitled "**Ecology, Ethology and Developmental Biology**" has been designed so as to cover the unit-wise syllabus of MZO-07 course for M.Sc. Zoology (Final) students of Vardhman Mahaveer Open University, Kota. The basic principles and theory have been explained in simple, concise and lucid manner. Adequate examples, diagrammes , photographs and self-learning exercises have also been included to enable the students to grasp the subject easily. List of books suggested for further study will be a great help the students. The unit writers have consulted various standard books and internet as their reference on the subject and they are thankful to the authors of these reference books. Suggestions for the further improvement of the book will be thankfully acknowledged and incorporated in further editions.

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Unit - 1

The Environment, Habitat and Niche

Structure of the Unit

1.0 Objectives

After going through this unit you will be able to understand the following concepts:

- Abiotic and biotic environmental factors and interaction between them.
- Understanding about the Ecological law of minimum and law of tolerance
- Concept of Habitat and niche, niche width and overlap; fundamental and realized niche; resource partitioning; character displacement

1.1 Introduction

This is chapter is very important for a student before you proceed further about the study of ecology, you must have clear cut concepts and thorough understanding about the environment. Let's begin with fundamental question: What do you mean by environment? And answer certainly comes to be:-

The term environment means surroundings. It is a complex of many factors, living as well as non-living. The sum total of all surroundings of a living organism, including natural forces and other living things, which provide conditions for development and growth as well as of danger and damage.

Environmental factors can broadly be classified into Abiotic and Biotic. These factors affect not only interact within but also influence the other. Life in fact is a sum total of such interactions. Abiotic factors are especially important because they directly affect how organisms survive.

1.2 Physical Environment

Abiotic components are the non living ecological factors that affect living components during any part of their life. They can broadly be classified into physical and chemical.

Abiotic factors come in all types and can vary among different ecosystems. For example, abiotic factors found in aquatic systems may be things like water depth, pH, sunlight, turbidity (amount of water cloudiness), salinity (salt concentration), available nutrients (nitrogen, phosphorous, etc.), and dissolved oxygen (amount of oxygen dissolved in the water). Abiotic variables found in terrestrial ecosystems can include things like rain, wind, temperature, altitude, soil, pollution, nutrients, pH, types of soil, and sunlight.

The boundaries of an individual abiotic factor can be just as unclear as the boundaries of an ecosystem. Climate is an abiotic factor which is made up of so many individual factors.. Even natural disasters, such as earthquakes, volcanoes, and forest fires, are also abiotic factors. These types of abiotic factors certainly have drastic effects on the ecosystems they encounter.

Physical environment includes the medium and the climate respectively.

There are basically four types of media that include: Soil, Water, Air, Bodies of other organisms

Climate on the other hand is the average of atmospheric components in a given area. This includes: Humidity, Light, Wind, Rainfall, Temperature etc.

Abiotic components also include the chemical factors of an environment like gases such as oxygen, CO2 etc., Hydrogen ion concentration, nutrients, hydrogen sulphide etc.

The activities and growth of plants and animals are a result of several of these abiotic factors. The quantity of the abiotic components present in the ecosystem is known as 'the standing stage'.

1.2.1 Soil - Edaphic Factors

Soil is the upper layer of earth which is formed by the weathering of the underlying rocks. Study of soil is called **Pedology**. Soil not only provides support but also nutrition, water and required oxygen to the organisms. Formation of soil is called paedogenesis. Soil not only contains inorganic but also the organic component which is added to it through decomposition of dead and decaying organism. This black colored organic matter which is added to the soil is called humus and the process humification. This process starts from the debris of trees and plants which are added to soil. This debris is called litter. The litter is composed of dead leaves, twigs, wood, dead roots and various plant products. Just below the fresh litter often occurs the material derived from preceding season’s litter in which decay or microbial decomposition has set in. This is called duff. The litter is decomposed by soil microbes such as bacteria, actinomycetes and other fungi. The products of decomposition include various types of inorganic and organic plant nutrients. They are all incorporated into mineral particles which then become dark in color.

Humus includes two types of organic matter the partially decomposed organic matter derived from litter and excreta of soil animals like centipedes, millipedes, earthworms, mites, grass-hoppers, etc. which feed on the litter of plant material. Gradually the humus is completely decomposed into simple compounds like carbon dioxide, water and minerals salts by a process called mineralization.

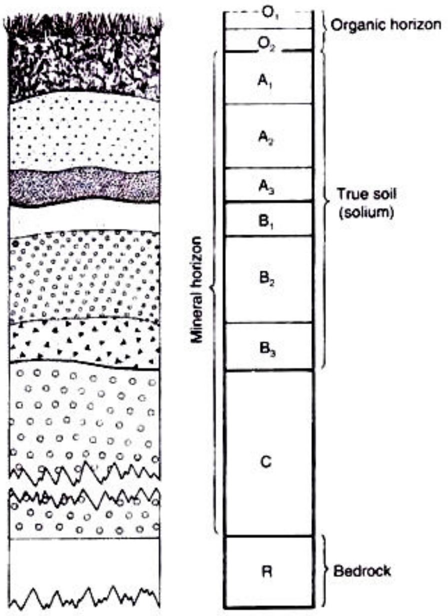

Fig. 1.10. **A generalized profile of soil.** **O_1**: Loose leaves and organic debris; **O_2**: organic debris partly decomposed or matted; **A_1**: A dark colored horizon with a high content of organic matter mixed with mineral matter; **A_2**: A light colored horizon with maximum leaching; **A_3**: Transitional to B but more like A than B; **B_1**: Transitional layer but more like A than B_2; **B_2**: A deeper colored horizon of maximum accumulation of clay minerals or of iron and organic matter; **B_3**: Transitional to C; **C**: Weathered material (regolith); **R**: Consolidated bedrock.

Soil Profile:

Soil in its cross section includes various layers called the horizons (see Fig.1.10) namely:

A Horizon: This is the topmost soil in which the vegetation grows and various biological activities occur. It is further subdivided into: A_1- which is the top layer consisting of freshly fallen leaves and A_2-$_3$-consisting of various organic substances in various stages of decomposition. It also consists of humus.

B Horizon: It has iron and aluminum compounds in it. It also has clay and humus.

A and B Horizons together form the true soil.

C Horizon- It has large masses of weathered mineral material.

R-Horizon: It contains un-weathered parent rock material.

Soil texture - The texture of the soil is variable from particles like clay to larger particles like sand. Sandy soils are suitable for growing plants and are well aerated and are easy to cultivate. Sandy soils cannot retain much water and contain few nutrients required for plant growth. In fact loamy soils are best suited for plant growth as they contain equal amounts of sand, clay and silt.

Soil air - Soil air is the spaces between the soil particles where it is not filled with soil water. The soil air determines the firmness of the soil.

Temperature of soil - Temperature of the soil is an important factor, temperature of soil below 30cm is said to be constant but there are seasonal variations. The decaying caused by decay-causing microorganisms is low at lower temperature.

Soil water - Soil water is classified into three types - capillary water, hygroscopic water and gravitational water. Of these capillary water is of great importance for plant life. Field capacity is the sum of capillary, hygroscopic and combined water. It is the maximum amount of water that soil can hold after the draining away of gravitational water.

Soil pH - pH of the soil affects the biological activity in the soil and certain mineral availability. The pH influences the growth and development of plants. The soil pH lies between 2.2 and 9.6. Soils are alkaline in arid and acidic in tropical areas.

The organisms and the decaying matter in the soil are known as soil solution and it increases the fertility of the soil. Microflora of the soil includes bacteria, blue green algae, fungi etc. while the microfauna has protozoans, mites, nematodes, rotifers etc.

1.2.2 Light

Light is the primary source of energy to almost all ecosystems. The light energy is used by the autotrophs to manufacture food by the process of photosynthesis by combining together other inorganic substances. It is evident; therefore, that light has a very profound ecological importance. The factors of light like its quality, intensity and the length of the light period play a vital role in an ecosystem. The study of light as an ecological factor is complicated by the fact that the sun emits not only the light rays used for assimilation, but in addition heat rays and ultraviolet rays, both of which influence many other processes in the plant. The table given below gives some idea of the action of different parts of the spectrum upon the living plant.

Radiation	Wave length (in μ)	Action on the Plant
Roentgen	0.00001—0.00018	Extremely harmful
Ultra-violet	0.012—0.40	Very harmful in large quantity
Violet Blue	0.40—0.49	Phototropism, morphological effect
Green Red	0.49—0.76	Photosynthesis and flowering
Infra Red	0.76—*circa* 600	Temperature effects, photosynthesis and flowering
Electric rays	2 nm. to indefinite	Not certainly known

- The quality of light affects the aquatic ecosystems, the blue and red light is absorbed here and it does not penetrate deep into the water. Some algae have specialized pigments that absorbs the other colors of light.
- The intensity of light depends upon the latitude and the season of the year. During the period from March to September the Southern Hemisphere receives less than 12 hours of sunlight while it receives more than 12 hours of sunlight during the rest of the year.
- 10 % of light falling on water is reflected back while the rest is modified in terms of Intensity, distribution and spectral composition. Suspended particles in water in fact reduce the intensity of light by scattering. This reduction in light intensity is called Extinction rate. Below 200 meters there is no light penetration and is called the 'Zone of Perpetual Darkness'.
- Light affects various activities such as metabolism, reproduction, development, skin pigmentation etc. Cave animals where there is no light lack pigmentation. The coloration of few animals, protect them from enemies and is known as protective coloration. Some of them match their backgrounds like Phylliumos leaf insect matches the green leaves. Some animals on the other hand are able to change their colors as per the surroundings. This ability is known as 'Visual stimulus'. It is wide spread amongst crustaceans, insects, amphibians and reptiles. The effect of light on movement is called **Photokinesis**. Movement of an organism in response to light is called phototaxis. On the other hand when only a part of the organism moves towards light it is known as phototropism.
- Similarly response of the organism towards length of day is called is called **photoperiodism**. Some plants flower only during a certain time

of the year. One of the factors is due to the length of dark period. Depending on the intensity of light the plants are classified as short-day plants (Example *Chrysanthemum*) Long-day plants (Examples - Spinach, barley, wheat, radish, clover, etc.) Day-neutral plants (Examples - Tomato, maize, etc.)

- Activities in animals are also affected by day duration.
- **Luminiscence or Phosphoroscence** is the light of biological origin. It is common in oceans and land during night but not usually found in fresh water. It serves various functions such as Illumination, Recognition, lure and warning. For e.g. Squids are able to keep together in dark because of light flashing. Similarly when attacked cuttle fishes secrete black secretion into the water and are able to escape.

1.2.3 Temperature

Temperature influences the distribution and growth of plants and animals. Range of temperature varies markedly in various environments, from below zero to greater than 100 0 C in hot springs. Changes in the temperature also occur during daytime. These are called diurnal changes. These are prominent on land than in water.

Besides there is thermal stratification also best studied in water bodies. The surface temperatures are normally higher or lower as compared to basal layers as the maximum density of water is reached at 4 0 C. Between these extreme gradients there occurs a zone of rapid change where the temperature changes at a rate of 1 0 C. This is called the Thermocline. The upper warmer layer during summers is called the Epilimnion while the lower cooler layer is called the Hypolimnion.

Depending on the range of tolerance of temperature the organisms are either Eurythermal of Stenothermal. While the first group includes animals with a wide range of temperature tolerance e.g. humans the latter consists of organisms with a narrow range such as fishes and reptiles.

On the basis of body temperatutres animals are classified into two groups:

A) Homoeothermic animals: In these animals such as mammals they regulate their body temperatures at a constant level irrespective of environmental temperatures.

B) Poikilothermic animals: In these animals body temperatures fluctuate with that of environment e.g. fishes, amphibians.

Mechanisms for meeting temperature variations:

a) Hibernation: It is the period of dormancy which occurs in cold blooded animals during winter season. In this period these organisms hide themselves under rocks or in crevices. Their metabolic. activity is extremely low during this period and they derive the required energy from stored fats and glycogen. Some animals are solitary hibernators while others hibernate in groups.

b) Aestivation: Just like hibernation this is the period of dormancy shown during summers. It is usually found in insects and some vertebrates. Lung fishes for example spend their summers in mud cocoon. Insects show dormancy in the form of Diapause.

c) Thermal Migration: To avoid extreme of temperatures animals migrate to places of favourable conditions. It is a common occurrence in Toads, turtles etc. Even bears, deers move to valleys from mountains during winters. Migration is most elaborate in birds which travel thousands of kilometers to places of their liking.

d) Formation of spores, cysts etc.: Certain plants, animals produce spores, cysts, pupae, eggs to resist extremes of temperatures. Plants produce structures like rhizomes, stolons to tide over unfavourable conditions.

Effects of temperature in plants and animals:

a) Metabolism: Most of the metabolic activities are under the control of temperature as these activities are controlled by enzymes which are influenced by temperature. Initial increase in temperature increases the enzymatic activity however after a certain limit retardation starts.

b) Reproduction: There is a direct influence of temperature on reproduction. Some animals breed in summers like while others breed in winters. Maturation of sex cells and liberation of gametes takes place at a particular temperature in certain species. In Blow fly number of eggs laid increases upto 32.5 0C after which the number comes down. Similarly in Grasshopper *Melanopus* the optimum temperature for egg production is 39 0C, below which the production comes down.

c) Sex Ratio: In certain rotifers and daphnids under normal temperature they produce parthenogenetic eggs which develop into females. However with the rise in temperature, they give rise to sexual eggs which may develop into males or females. Interestingly, in plague flea

Xenopsylla males outnumber females on days when temperatures are between 21 0C and 250C. However on cooler days the numbers are reversed.

d) Growth and Development: Development of eggs and even the maximum size attained depends in certain species depend upon temperature.

e) Structural and Behavioural changes: Several such modifications are seen. In Drosophila *Melanogaster* temperature affects position of genes and chromosomes during crossing over resulting in various structural changes.

f) Cyclomorphosis: In certain planktons body form changes with the seasonal changes in tempetrature. This is best exhibited in cladocerans like *Daphnia*. In winters thay have a round head which attains a helmet like projection during spring and in summers this projection attains maximum size. This is an adaptation which helps in floating as the buoyancy of the water is reduced with rising temperatures.

Gloger's Rule: In warm humid climates many animals like insects and mammals are darker in color as compared to their counterparts living in cool and dry places.

Jordan's Rule: Temperature is also believed to control the number of vertebrae in certain fishes. In these the fishes of cooler waters have more vertebrae as compared to warm water forms.

Allen's rule: Size of exremities in animals like ears, tails neck etc. is also controlled by temperature. These are relatively smaller in cooler parts. Eskimos have comparatively small arms and legs. This adaptation seems to reduce heat loss in cooler temperatures.

Bergman's rule: This rule states that races of species inhabiting cold regions are larger in size to their counter parts inhabiting warmer regions. It is explained that larger body ensures less surface area per unit weight resulting in lesser heat loss. Antarctic penguins are much larger is size as compared to equatorial Galapagos forms.

1.2.4 Water

Habitats of animals and plants vary widely from aquatic environments to the dry deserts. Water is essential for life and all the biotic components of the ecosystem are directly dependent on water for survival. It covers almost 73% of earth and is a medium for vast aquatic life. Moreover its not just a medium it has several unique properties which makes it indispensable for life. Some of these are as following:

a). Universal Solvent: No other liquid has such exclusive properties as water which makes it a universal solvent. It is because of this property that it has several minerals, salts amd gases dissolved in it which support life.

b). Surface Tension: It is the cohesive force between the molecules of water by which they are held together. This property helps in movement of water in and outside the cell as well as movement of ground water.

c). Viscosity: Planktonic organisms able to swim passively without any special swimming organ.

d). Density: The freezing point of sea water is -2.50C and that of fresh water 00C because of which ice floats on water and the life inside can live comfortably.

e). Heat Conduction: Since water has the highest heat conduction property which allows it to maintain a constant temperature.

f). Specific Heat: It is the amount of heat required to raise the temperature of I ml. of water by 10C. Therefore it can withhold large amount of heat without much variation in the temperature. It is because of this that temperature of water bodies is maintained.

g). Salinity: As salinity is maintained in marine water it allows free movement of animals.

h). Pressure: It increases with the depth of water, and to overcome this various adaptations are found which allows animals to counter such high pressures. These include air bladders and fluid filled cavities.

Based upon their water requirements plants are classified as:

- Hydrophytes (Example - Water lilies)
- Mesophytes (Example - Sweet pea, roses)
- Xerophytes (Example - Cacti, succulent plants)

Land animals are prone to desiccation and these animals show various types of adaptations to this. Some of the adaptations seen in terrestrial animals are:

- Body covering which limits loss of water.
- Some animals have sweat glands which are used as cooling devices.

- The tissues of some animals like camel are tolerant to water loss.
- Some insects are said to absorb water from the water vapor directly from the atmosphere.

1.2.5 Rainfall and Other Atmospheric Precipitations

Rainfall affects indirectly through the medium of other ecological factors. As it directly affects the amount of available soil water, the annual rainfall is a major factor in determining the distribution of plants and animals. Many plants like epiphytes and lithophytes have no source of water other than direct atmospheric precipitations. Such plants have special organs for the absorption of water from atmospheric precipitation. For instance, occurrence of aerial roots with special water absorbing spongy tissue called velamen. In animals also this ability (hygroscopic) is found in certain animals such as desert dwelling lizards.

The deposition of dew in areas with scanty rainfall is of great importance to maintain vegetation. In the sub-tropical tracts which receive only negligible amount of rains, strong deposition of dew takes place during dry season. Breazeale (1950) has quoted instances when the leaves of certain plants absorb water from saturated atmosphere, and this water exudes through the roots into the surrounding soil which, consequently, may attain field capacity.

Too much rainfall in a particular region determines the type of vegetation not only pertaining to that of humid climate but also types of plants with adaptation for soil percolated with water and against heavy showers. For instance, leaves of the plants growing in equatorial forests have drip-tip and furrows so that excess of water can immediately be removed. The moist climate increases the longevity of plants and their leaves, whereas the dry climate shortens the vegetative period, checks blooming, setting of fruits and maturation of seeds. Aridity also enhances the resting period.

Temperature is perhaps the most important environmental factor which determines the effectiveness of rainfall. Light rains in hot, dry weather will usually have no effect upon the soil moisture content, for the water does not get down to the roots, and quickly evaporates from the soil surface. Heavy rains of short duration may also have little effect upon soil moisture, for the runoff may be great.

1.2.6 Atmospheric Humidity

This is a very important climatic factor which directly affects the vegetation. It is so, chiefly because of its effect on the rate of transpiration in plants. The most important environmental factor that effects atmospheric humidity is temperature.

In the atmosphere, water is present in the form of water vapors. This is called atmospheric humidity. Evaporation of water from earth surface and transpiration from plants are the main cause of atmospheric humidity. Clouds and fog are the visible forms of humidity.

Humidity is described in three different terms:

(a) **Specific Humidity:**It refers to the "amount of water vapours present per unit weight of air".

(b) **Absolute Humidity:**It refers to the "amount of water vapours present per unit volume of air".

(c) **Relative Humidity:**It refers to the "amount of water vapours actually present in the air, and is expressed as percentage of the amount which the air can hold at saturation at the existing temperature". Absolute and relative humidity change with the changes in temperature.

Absolute humidity is maximum near the equator and it gradually declines as we proceed towards poles. Relative humidity is also maximum near the equator but decreases in the subtropical regions and increases once again in the temperate regions. Thus, the relative humidity is affected by temperature as well as latitude.

Humidity affects structure, form and transpiration in plants. In higher temperature the relative humidity is low and exposed water quickly evaporates and thus the rate of transpiration increases. Transpiration is one of the leading functions through which the habitat of a plant is determined. For instance, the highly humid air within a lowland forest or in a sheltered mountain gorge (narrow defile between mountains), is greatly responsible for the delicate and obviously moisture loving characters of the plants inhabiting that area. Plants like orchids, mosses and lichens depend on atmospheric humidity for their water requirement.

1.2.7 Wind

Wind is also an important ecological factor which affects both directly and indirectly. The direct effects of wind are to be seen in the regions which are quite often exposed to violent winds. Violent winds often break off twigs or branches of plants and sometimes even uproot the trees and shrubs. Such an effect of wind often prevents the growing of larger trees above a certain height.

The vegetation of such areas is mostly composed of species which have a prostrate habit of growth and a tenacious underground root or rhizome system.

1.3 Biotic Environment

The biotic components of the ecosystem which includes the plants, animals and microbes interact and are dependent on the abiotic factors. There are interactions among them can be defined as inter-specific and intra-specific Inter-specific Interactions

- Since a community comprises all the species that occur at a particular location, one of the most important things about communities is how the species interact with one another.
- Four different types of interactions between different species (interspecific interactions) have been identified:

Competition

Two organisms mutually harm one another

Predator–prey or parasite–host

One organism benefits, the other is harmed

Mutualism

Both organisms benefit

Commensalism

One organism benefits, the other is not affected

Interacting species have a tremendous influence on the size of each other's populations. The various mechanisms for these biotic influences are quite different from the way in which abiotic factors affect the size of populations. Biotic factors also regulate the size of populations more intensely. The influence of biotic interactions can occur at two different levels. Inter-specific effects are direct interactions between species, and the intra-specific effects represent interactions of individuals within a single species. The various types of interactions can be summed up as below:

Relationships between individuals of different species.		
Type of Interaction	Effect of interaction	Examples
Competition	Both species are harmed (population growth rates are reduced).	Oak trees and maple trees competing for light in a forest, wading birds foraging for food in a marsh
Predation Parasitism	One species benefits, one is harmed.	Predation: wolf and rabbit Parasitism: flea and wolf
Mutualism	Both species benefit. Relationship may not be essential for either.	Humans and house pets, insect pollination of flowers
Commensalism	One species benefits, one is not affected.	Maggots decomposing a rotting carcass
Amensalism	One species harms another (typically by releasing a toxic substance), but is not affected itself.	Allelopathy (plants that produce substances harmful to other plants): rye and wheat suppress weeds when used as cover crops, broccoli residue suppresses growth of other vegetables in the same plant family

1.3.1 Neutralism

Neutralism is the most common type of interspecific interaction. Neither population directly affects the other. What interactions occur are slight and indirect. The simple presence of the two species should not directly affect the population level of either. An example of neutralism would be the interaction between rainbow trout and dandelions living in a mountain valley.

1.3.2 Competition

When two or more organisms in the same community seek the same resource (e.g., food, water, nesting space, ground space), which is in limiting supply to the individuals seeking it, they compete with one another. If the competition is among members of the same species, it is called intra-specific. Competition among individuals of different species it is referred to as inter-specific competition. Individual's in populations experience both types of competition to a greater or lesser degree.

Competition may be the result of two different processes: exploitation or interference. Competition by exploitation occurs between individuals when the indirect effects of two or more species or individuals reduce the supply of the limiting resource or resources needed for survival. The exclusion of one organism by another can only occur when the dominant organism requires less of the limiting resource to survive. Further, the dominant species must be able to reduce the quantity of the resource to some critical level with respect to the other organism. Resource exploitation, however, does not always cause the exclusion of a species from a community. It may just cause the species involved in this interaction to experience a reduction in their potential growth.

Competition by interference occurs when an individual directly prevents the physical establishment of another individual in a portion of a habitat. Established plants can preempt the invasion and colonization of other individuals by way of dense root mats, peat and litter accumulation, and mechanical abrasion.

1.3.3 Amensalism

Amensalism is an interaction where one species suffers and the other interacting species experiences no effect. One particular form of amensalism is allelopathy which occurs with plants. Allelopathy involves the production and release of chemical substances by one species that inhibit the growth of another. Allelopathic substances range from acids to bases to simple organic compounds. All of these substances are known under the general term: secondary substances. Secondary substances are chemicals produced by plants that seem to have no direct use in metabolism. A good example of a secondary substance is the antibiotic juglone which is secreted by Black Walnut (*Juglans nigra*) trees. This substance is known to inhibit the growth of trees, shrubs, grasses, and herbs found growing near Black Walnut trees. In the chaparral vegetation of California, certain species of shrubs, notably *Salvia leucophylla* (mint) and *Artemisia californica* (Sagebrush) are known to produce allelopathic substances. Often these chemicals accumulate in the soil during the dry season reducing the germination and growth of grasses and herbs in an area up to 1 to 2 meters from the secreting plants.

1.3.4 Mutualism

Mutualism is the name given to associations between pairs of species that bring mutual benefit. The individuals in the populations of each mutualist species grow and/or survive and/or reproduce at a higher rate when in the presence of individuals of the other species. This type of interaction is an extremely widespread phenomena. For example, most rooting plants have mutualistic associations with fungal mycorrhizae. *Mycorrhizae* increase the capability of plant roots to absorb nutrients like nitrogen and phosphorus. In return, the roots of the host provide support and a constant supply of carbohydrates for consumption.

Mutualistic interactions between species can be of two types: symbiotic or nonsymbiotic. In a symbiotic mutualism, individuals interact physically and their relationship is biologically essential for survival. At least one member of the pair cannot live without close contact with the other. For example, the fungal-algal symbiosis that occurs in lichens. The morphological structure of a lichen is a mass of fungal hyphae that forms around a small colony of algae cells. In this mutualism, the alga produces carbohydrates and other food by products through photosynthesis and metabolism, while the fungus absorbs the required minerals and water to allow for these processes to occur.

More common in nature is the non-symbiotic mutualism. In this interaction, the mutualists live independent lives yet cannot survive without each other. The most obvious example of an interaction of this type is the relationship between flowering plants and their insect pollinators.

1.3.5 Commensalism

It is an association between members of different species in which only one is benefited and neither is harmed. Examples are lianas. Lianas are vascular plants rooted in the ground and using other plants to maintain their erectness, e.g. *Tinospora*. Similarly Epiphytes are plants growing on other plants. Many orchids, bromeliads are examples.

1.3.6 Predation, Parasitism, and Pathogens

Pathogens, parasites, and predators obtain food at the expense of their hosts and prey. These processes are basic to the entire grazing food chain above the autotroph level. Predators tend to be larger than their prey and consume them from the outside. A parasite or pathogen is smaller than its host and consumes it either from the inside or from the outside of the organism.

It is easy to believe that the predator-prey interaction is somehow detrimental to the prey population. This idea has led to extensive efforts to control predator populations in the name of wildlife conservation. However, functional relationships between predator-prey between species, within natural ecosystems, have coevolved over long periods time creating a dynamic balance between their interacting populations. Thus, the population sizes of predator and prey species are inter-regulated by delicate feedback mechanisms that control the densities of both species.

A classic example of the balance between predator and prey involves the prickly pear cactus, *Opuntia* spp. In the 19th century, prickly pear cactus was introduced into Australia from South America. Because no Australian predator species existed to control the population size of this cactus, it quickly expanded throughout millions of acres of grazing land. The presence of the prickly pear cactus excluded cattle and sheep from grazing vegetation and caused a substantial economic hardship to farmers. A method of control of the prickly pear cactus was initiated with the introduction of *Cactoblastis cactorum*, a cactus eating moth from Argentina, in 1925. By 1930, densities of the prickly pear cactus were significantly reduced.

Sometimes predator species can drive their prey into localized extinction. In complex communities, this does no particular harm to the predator if several other species exist as alternative prey..

The **protocooperation** is defined as the process in which two organisms of different species are present and in which both the organisms are mutually benefitted and they can live independently. It includes the red and yellow billed ox pecker. They form a protocooperation with the rhinoceros. The birds feed on the parasites present on the skin of rhinoceroes and relieve him of the parasites. Similarly, the crocodile bird goes inside the mouth of crocodile and removes the leeches.

The **Gause Hypothesis** is also known as the principle of competitive exclusion. It states that out of the two species which grow together one is eliminated and the other one survives. At few occasions more than one species can survive. The species which compete they coexist due to their specializations. The Darwin discovered around 14 finches of species in the Galapagos Islands. They all have different feeding habits. The Serengeti plains have around 20 species of antelopes in the same area. There are many plants which can grow by their roots which are of different lengths.

The mimicry is defined as the process of resemblance of organism to the other organism or with the other object so that they can be concealed or protected as the time demands. Mimic is an organism which exhibits the mimicry. The model is defined as an object which resembles a mimic. In this type the color, form, pattern and scent of an organism resemble to the other organism or the surrounding objects. It helps the organism to protect it from predator and help in the easy trapping of prey. It also helps to secure pollination in the orchid. The prey develops a mimicry which is known as the protective mimicry. The predator develops a mimicry which is known as the aggressive mimicry. The protective mimicry is of different types. It can be concealing or warning. In concealing type the organism resembles the surroundings so that they cannot be detected easily. It includes the stick insect, larva of moth and the leaf insect. These different types of organism resemble the twigs and green leaf. In the warning type the organism resembles the poisonous organisms. It includes the palatable butterfly and non palatable butterfly. There is another type of mimicry which is known as the Batesian mimicry. In this an edible species resemble a non edible species. When the non edible species resemble each other it is referred as the Mullerian mimicry. This mimicry which is discussed above is included in the protective mimicry. The aggressive mimicry is of different types. It can be concealing and alluring. In concealing type the predator resembles the surroundings so that they cannot be detected easily. They hide and strike suddenly. It includes the praying mantis. In alluring type the predator attracts the prey by resembling an object which is liked by the prey. It includes the mouth of African lizard which resembles a flower. The spider also resembles an orchid flower.

1.4 Biotic and abiotic interactions

The environmental factors, both biotic and abiotic; which of these factors govern their distribution and abundance, and how these factors have influenced their adaptations and life history strategies. We also know that it is not only the environment and its physical and biotic factors which affect the organism but the organism is also able to modify the environment to a certain extent (Gaia Hypothesis). The hypothesis states that the earth's atmosphere would not support life without regulation by the totality of life in the biosphere.

So far we have studied about the number of environmental abiotic factors such as light, temperature, water, humidity, currents and pressures, general weather conditions, soil and fire (all physical factors), and atmospheric and dissolved gases, pH, nutrients and food (all chemical factors), and biotic factors (plants and animals of the same and other species) effect the distribution and abundance of organisms in different habitats.

The two concepts combined form the Liebig- Blackman law. Any condition or factor that affects an organism by exceeding the limits of tolerance is called a limiting factor.

A combination of Liebig-Blackman law of minimum and Shelford's law of limits of tolerance gives us a combined concept of limiting factors which is a better expression of the environmental conditions affecting the organisms in natural ecosystems.

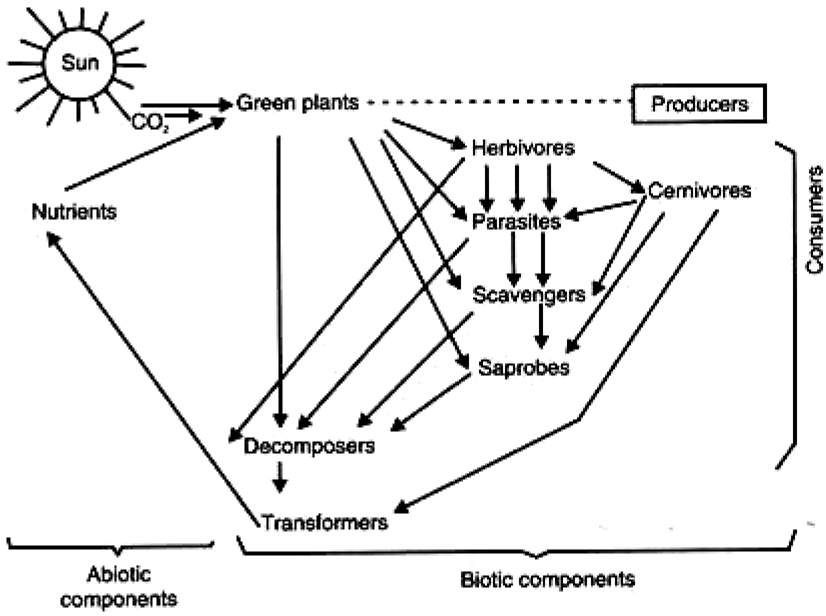

Fig. 1.2 Schematic -Interaction between the Abiotic and Biotic factors

1.5 Ecological law of minimum and law of tolerance

1.5.1 Leibigs law of Minimum

Justus von Liebig, generally credited as the "father of the fertilizer industry", while studying the relationship between availability of essential elements and crop yield, formulated the law of the minimum which states that if one crop nutrient is missing or deficient, plant growth will be poor, even if the other elements are abundant or the growth of palnt is dependent upon the amount of food stuff presented to it in the minimum quantity. It is also called the ‘Law of Minimum’.

Liebig compared potential of a crop to a barrel with staves of unequal length. The capacity of this barrel is limited by the length of the shortest stave and can only be increased by lengthening that stave. When that stave is lengthened, another one becomes the limiting factor.

Liebig's Law has been extended to biological populations. For example, the growth of an organism such as a plant may be dependent on a number of different factors, such as sunlight or mineral nutrients (e.g. nitrate or phosphate). The availability of these may vary, such that at any given time one is more limiting than the others. Liebig's Law states that growth only occurs at the rate permitted by the most limiting.

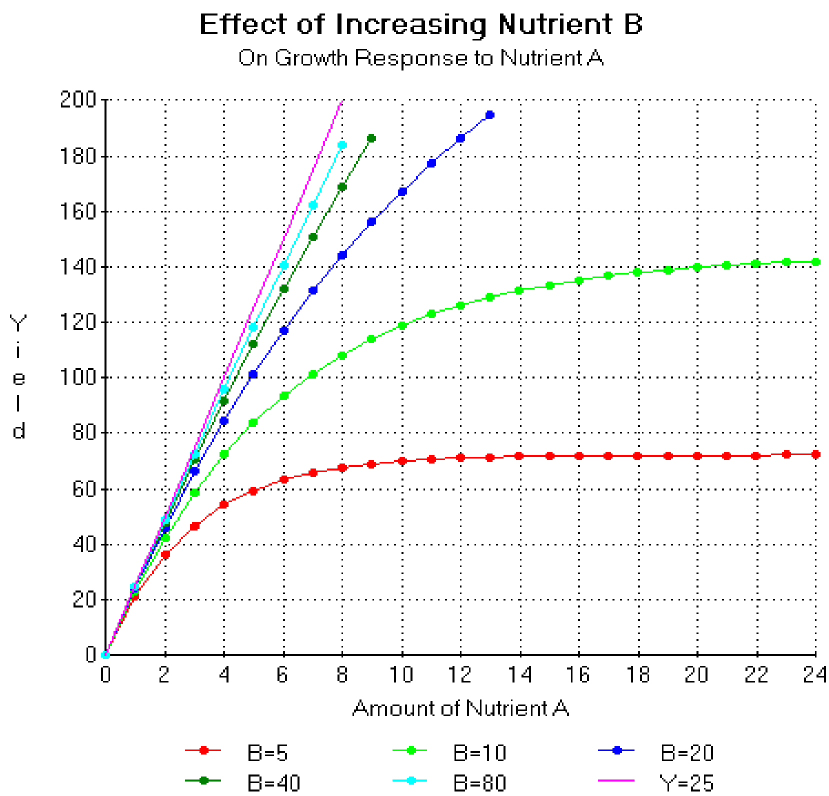

Fig 1.4 The graph showing the influence of Nutrient B over Nutrient A

Blackmann further studied the phenomenon in plants and stated that the rate of photosynthesis is governed by factors that are operating at a limiting capacity.

However in view of later studies it has been found that Law of Minimum is only applicable under steady state condition i.e. inputs are equal to outputs. However during transitional periods it changes.

Secondly studies have shown that high level of one factor will modify limiting effect of second. This phenomenon is known as 'Factor Interaction'. For example mollusks utilize strontium in place of calcium for their shells when the former is available in abundance. Similarly there is less requirement of Zinc for plants growing in shade as compared to others growing under sunlight.

1.5.2 Shelford's law of tolerance

Organisms may be limited in their growth and their occurrence not only by too little of an element or too low an intensity of a factor but also by too much of the element or too nigh intensity of the factors.

For example, carbon dioxide is necessary for the growth of all green plants, small increase in concentration of carbon dioxide in the atmosphere will, under certain circumstances; increase the rate of plant growth, but very considerable increases become toxic. Likewise, small additions of arsenic to the human diet actually have a tonic effect, further increase in the dosage, however, soon proves fatal.

The idea that factors could be limiting at their maximum as well as minimum quantities was incorporated in law of tolerance formulated by V. E. Shelford in 1913. This law postulates that each ecological factor to which an organism responds has maximum and minimum limiting effects between which lies a range or gradient that is now known as the limits of tolerance.

Between the lower and upper limits of tolerance lies a broad middle sector of a gradient which is called the zone of compatibility, the zone of tolerance, the biogenetic zone or the zone of capacity adaptation.

The region at either end of the zone of compatibility is called the lethal zone or the zone of resistance or zone of intolerance. The zone of compatibility too includes a broad range of optimum and narrow zones of physiological stresses in between the range of optimum and lethal zones.

Upper and lower limits of tolerance are intensity levels of a Factor at which only half of the organisms can survive. These limits are sometimes difficult to determine, as for example with low temperature, organisms may pass into an inactive, dormant, or hibernating state from which they may again become functional when the temperature rises above a threshold at high temperatures, there may be similar inactivation or aestivation before the lethal level is attained. Even without dormancy occurring, there are normally zones of physiological stresses before the limits of tolerance are reached.

The species as a whole is limited in its in activities more by conditions that produce physiological discomforts or stresses than it is by the limit of tolerance themselves. Death verges on the limits of tolerance, and the existence of the species would be seriously jeopardized if it was frequently exposed to these extreme conditions.

Therefore, in retreat before conditions of physiological stress there is a margin of safety, and the species adjusts its activities so that limits of tolerance are avoided. There is a variation in hardiness of individuals within a species, so that some hardy individuals find existence possible under conditions that disrupt other individuals. The population level of a species becomes reduced before the limits of its range are actually reached.

Further, species vary in their limits of tolerance to the same factor. For example, the Atlantic salmon spends most of its adult life in the sea, but goes annually into fresh-water streams to breed. Most other marine fishes are killed quickly when placed in freshwater, as are fresh-water fishes when placed in salt water. The following terms are used to indicate the relative extent to which organisms can tolerate variations in environmental factors.

The relationship between populations and environmental factors can be shown in the shapes of the tolerance curves for the specific variables shows two such curves, one in which the optimum is very broad and one in which it is quite definite. The prefix steno-means that the species, population, or individual has a narrow range of tolerance and the prefix eury-indicates that it has a wide range.

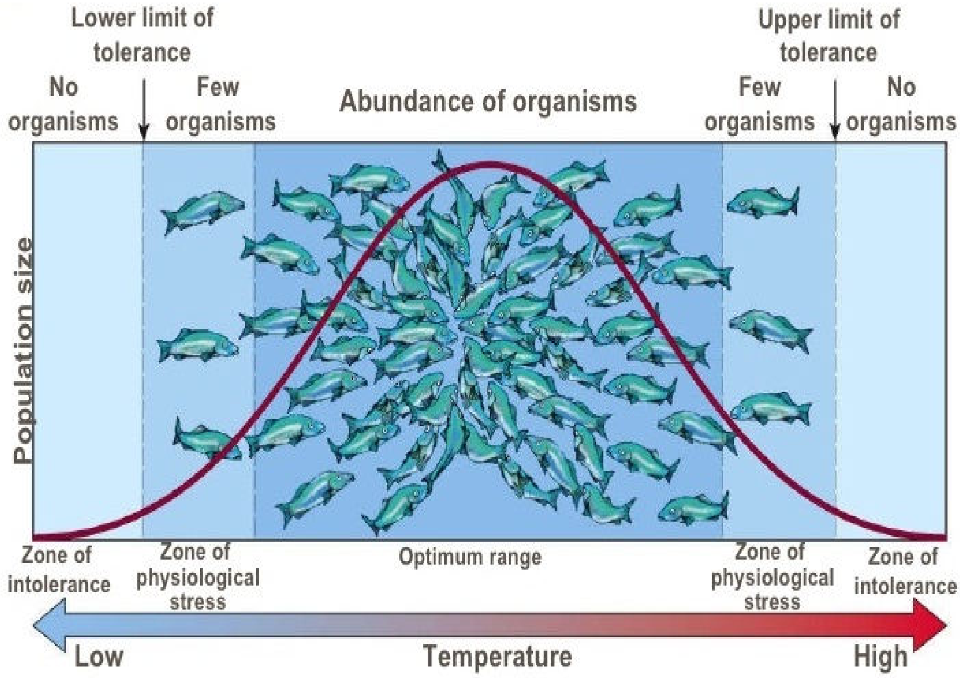

Fig. 1.3 Exhibiting the relationship between the temprature range and population living therein
Courtsy: Thomson Higher Education;2007

Moreover, a plant or animal may have a wide range of tolerance for one factor in the environment, but a relatively narrow range of tolerance for another condition. Thus, we find that some species of fresh-water fishes are eurythermal but they are stenohaline.

However recent studies have shown that all physical requirements may be well within the limits of tolerance for an organism, but the organism may fail due to biological interrelations such as competitions and the predations

Some subsidiary principles to law of tolerance may be stated as follows:

1. Organisms may have a wide range of tolerance for one factor and a narrow range for the other.

2. Organisms with side range of tolerance for limiting factors are likely to be most widely distributed.

3. In some cases where conditions are not optimal for a species with respect to one ecological factor then the limits of tolerance may be reduced for other ecological factors, like some fishes are eurythermal having a wide range of tolerance for temperature but are stenohaline i.e. lower range if tolerance for salt. However, lowering of temperature, results in reduction of tolerance to law salinity.

4. Sometimes it may happen that an organism may not be living at the optimum range of a particular factor. in such cases the others physical factors are found to have great importance.

   Example: the cord grasses which dominates the east coast salt marsh areas, actually grows better in fresh water than in salt water. but in the nature it is found in only salt water, apparently because it can extrude salt from leaves better than any of its competitors.

5. The period of reproduction is a critical period, when environmental factors become limiting: an adult cypress tree will grow continually submerged in water or dry upland, but it cannot reproduce until there is moist unflooded ground.

6. Range of tolerance varies for geographical races of the same species.

1.6 Concept of Habitat and Niche

Niche v/s Habitat

A habitat is where an organism or a community of organisms' lives, and a niche is the specific place an organism has in an ecosystem. A habit can help define the niche of particular creature but cannot describe it entirely.

A habitat can range in size from a host creature where parasites live to a grove of trees or a pond to things much larger. They must provide the organisms that live there with what they need to survive such as food, water, oxygen and minerals. If the habitat provides these things to the organisms that live there, those creatures will stay in the habitat. If these needs are not met, however, the organisms that live there will move elsewhere.

A niche, on the other hand, reflects an organism's behaviors and other variables like wind or temperature that affect those behaviors. Evolution helps species adapt over time until it evolves to successfully fill a place within a certain environment. Some species evolve so well, however, that it may no longer be suited to another environment. It is also possible for similar environments to help similar species evolve that do not live close together. For example, cattle in North America and wildebeests in Africa are similar because they evolved in similar niches in their environments.

1.6.1. The Ecological Niche (width and overlap)

Ecological Niche: The term was first used by Grinnel in 1971. It is defined as the ultimate distribution unit within which each species is held by its structural and instinctive limitations. No two species can occupy the same niche. It is not to be confused with habitat. Habitat of an organism is the place where it lives i.e. some physical area. It may be as big as a sea or intestine of a termite. Ecological niche is the sum total of an organism's use of the biotic and abiotic resources in an environment

It includes: Space utilization, Food consumption, Temperature range and Moisture requirements

In simple terms when we compare Niche with habitat we find that Niche is like an occupation i.e. What an organism does. Habitat on the other hand is like an address where an organism lives. The difference can be explained through the example of wall lizard whose three species namely *Hemidactylus leschenautte* is found on large trees, *H. brooki* is found in houses while *H.reticularus* is found in rocks.

Ecological Niche is of much importance as it explains the difference between species at same physical place or at different places. The various aspects of Niche can be described as:

1. Spatial or Habitat Niche: It is concerned with the physical space occupied by the organism.
2. Trophic Niche: It is related to the trophic position of the organism. For e.g. two aquatic bugs Notonecta and Corixa live in the pond but occupy different trophic positions. On one hand Notonecta is a predator while Corixa feeds on decaying matter.
3. Mulifactor Niche: Niche is multidimensional, considering so many biotic and abiotic factors.

1.6.2. Fundamental Niche and Realized Niche

Interspecific competition occurs when two different species attempt to utilize the same resource and there is not enough of the resource for both species. As a result some species are not able to occupy their entire niche because of the presence or absence of other species. Observation of this phenomenon in nature has led to the concepts of fundamental and realized niches.

Fundamental niche: the set of resources a population is theoretically capable of using under ideal conditions

Realized niche: the resources a population actually uses. The realized niche may be smaller than the fundamental niche because of interspecific interactions such as:

Competition and Predation

This has been explained by **Joseph Connell's** Famous Experiments

Two species of barnacles live in a stratified distribution in the intertidal region along the Scottish coast.

Balanus is most concentrated in the lower intertidal area. *Chthamalus* is most concentrated in the upper intertidal area. The free-swimming larvae of each species can settle anywhere on the rocky shoreline, and presumably be able to grow to be an adult. Connell removed *Chthamalus* from the upper area, and no *Balanus* replaced it. Therefore it was inferred that *Balanus* could not survive in an area that experienced so much desiccation (due to low tides). *Balanus*'s realized niche was the same as its fundamental niche. Then Connell removed *Balanus* from the lower area and *Chthamalus* replaced it. It was inferred that *Balanus* was a more successful competitor in the lower intertidal zone. Thus the fundamental niche and realized niche for *Chthamalus* were not the same—its realized niche was smaller due to interspecific competition.

Ecological equivalents: Organisms that occupy the same niche in different geographical regions are called ecological equivalents. For e.g. different types of grasses are found in various grasslands but are all primary producers. Similarly kangaroos of Australlia are ecological equivalents of antelopes of North America as both are grazers.

Competition: The Competitive Exclusion Principle

The biologists Lotka and Volterra theorized that no two species with similar requirements for resources (food, shelter, etc.) could coexist in the same niche without competition driving one to local extinction.

Gause's Experiment

A Russian scientist, G.F. Gause, tested the Lotka–Volterra theory.

He grew two different species of *Paramecium* alone, under identical conditions. Their populations grew to their carrying capacity and leveled off. He put them together and discovered that one species died out (it couldn't compete). Conclusion: Two species competing for limited resources cannot coexist in the same place at the same time. This concept was named the competitive exclusion principle (or Gause's Principle).

1.6.3. Resource Partitioning

The process by which, natural selection drives competing species into different patterns of resource use or different niches. Coexistence is obtained through the differentiation of their realized ecological niches.

A consequence of Gause's competitive exclusion principle, If competition for a limited resource is intense, there are two possible outcomes:

One species drives the other to extinction.

Natural selection reduces the competition between the species.

Robert MacArthur of Princeton University did a famous study of five species of warbler (small insect-eating songbirds) in the late 1980s. It appeared that they all were competing for the same resources on spruce trees. On closer inspection, he realized the five species were each feeding on different parts of the tree and therefore eating different insects. In essence, each species had evolved to utilize a different portion of the spruce tree resource. They had subdivided the niche, partitioning the available resource to avoid direct competition with one another. This process became known as **resource partitioning.**

When species use different resources, this can help them to coexist. For example, some lizard species appear to coexist because they consume insects of differing sizes. Alternatively, species can coexist on the same resources if each species is limited by different resources, or differently able to capture resources. For example, different types of phytoplankton can coexist when different species are differently limited by nitrogen, phosphorus, silicon, and light. In the Galapagos Islands, finches with small beaks are more able to consume small seeds, and finches with large beaks are more able to consume large seeds. If a species' density declines, then the food it most depends on will become more abundant (since there are so few individuals to consume it). As a result, the remaining individuals will experience less competition for food.

Although "resource" generally refers to food, species can partition other non-consumable objects, such as parts of the habitat. For example, warblers are thought to coexist because they nest in different parts of trees. Species can also partition habitat in a way that gives them access to different types of resources. As stated in the introduction, *Anolis* lizards appear to coexist because each uses different parts of the forests as perch locations. This likely gives them access to different species of insects.

There are three types of differential resource utilization or partitiioning.

Temporal partitioning

Temporal resource partitioning occurs when two species eliminate direct competition by utilizing the same resource at different times. This can be on a daily scale (e.g. one species of spiny mouse feeds on insects during the day while a second species of spiny mouse feeds on the same insects at night, or on a longer, seasonal scale. An instance of the latter would be reproductive asynchrony, or the division of resources by the separation of breeding periods. An example of reproductive asynchrony would be two competing species of frog offsetting their breeding periods. By doing this the first species' tadpoles will have graduated to a different food resource by the time the tadpoles of the second species are hatching.

Spatial partitioning

Spatial resource partitioning occurs when two competing species use the same resource by occupying different areas or habitats within the range of occurrence of the resource. Spatial partitioning can occur at small scales (microhabitat differentiation) or at large scales (geographical differentiation). Microhabitat differentiation occurs when two competing species with overlapping home ranges partition a resource. Two examples would be different species of fish feeding at different depths in a lake or different species of monkey feeding at different heights in a tree. Geographical differentiation is when two competing species have non-overlapping home ranges and thus partition resources. An example might be given with monkeys again: two competing species of monkey using the same species of fruit trees, but in different areas of the forest.

Morphological differentiation

The final type of differential resource utilization is morphological differentiation or niche complementarity. Morphological differentiation happens when two competing species evolve differing morphologies to allow them to use a resource in different ways. A classic example of this is a study detailing the link between bumblebee proboscis lengths and flower corolla lengths (Pyke 1982). In this study, the long-proboscis bee species would preferentially feed on the long-corolla plants, the medium-proboscis bee species would feed on the medium-corolla plants, and so on. By evolving different proboscis lengths, several competing bee species are able to partition the available resources and coexist.

Coexistence without niche differentiation: exceptions to the rule

Some competing species have been shown to coexist on the same resource with no observable evidence of niche differentiation and in "violation" of the competitive exclusion principle. One instance is in a group of hispine beetle species. These beetle species, which eat the same food and occupy the same habitat, coexist without any evidence of segregation or exclusion. The beetles show no aggression either intra- or inter-specifically. Coexistence may be possible through a combination of non-limiting food and habitat resources and high rates of predation and parasitism, though this has not been demonstrated.

This example shows that the evidence for niche differentiation is by no means universal. Niche differentiation is also not the only means by which coexistence is possible between two competing species However, niche differentiation is a critically important ecological idea which explains species coexistence, thus promoting the high biodiversity often seen in many of the world's biomes.

Research using mathematical modelling is indeed demonstrating that predation can indeed stabilize lumps of very similar species. Willow Warbler and Chiffchaff and other very similar warblers can serve as an example. The idea is that it is also a good strategy to be very similar to a successful species or have enough dissimilarity. Also trees in the rain forest can serve as an example of all high canopy species basically following the same strategy. Other examples of nearly identical species clusters occupying the same niche were water beetles, prairie birds and algae. The basic idea is that there can be clusters of very similar species all applying the same successful strategy and between them open spaces. Here the species cluster takes the place of a single species in the classical ecological models.

1.6.4 Character Displacement

Brown and Wilson (1956) coined the term "character displacement," but the catalyst for the idea can be traced to the earlier disussed Gause experiment (1934). They observed that there are two species of Sitta bird. Species that occur in different geographical regions are said to allopatric while those occurring in the same region are said to be sympatric. The birds of the same region exhibited more morphological diversity as compared to the allopatric one "this tendency for characteristics to be more divergent in sympatric populations of two species than in allopatric populations of the same two species is called character displacement."

Ecological character displacement is a process of phenotypic differentiation of sympatric populations caused by interspecific competition. Such differentiation could facilitate speciation by enhancing reproductive isolation between incipient species.

It has been studied patterns for morphological variation in sympatric and allopatric populations of two hybridizing species of birds, the Common Nightingale (*Luscinia megarhynchos*) and the Thrush Nightingale (*L. luscinia*). nightingale species converged in overall body size and diverged in relative bill size in sympatry. Closer analysis of morphological variation along geographical gradients revealed that the convergence in body size can be attributed largely to increasing body size with increasing latitude, a phenomenon known as Bergmann's rule. In contrast, interspecific interactions contributed significantly to the observed divergence in relative bill size, even after controlling for the effects of geographical gradients. We suggest that the divergence in bill size most likely reflects segregation of feeding niches between the species in sympatry.

Interspecific competition for food resources can drive species divergence even in the face of ongoing hybridization. Such divergence may enhance reproductive isolation between the species and thus contribute to speciation.

A comparison of allopatric versus sympatric populations of species shows evolutionary evidence of competition in nature. Example: Galápagos finches.

When two species occur on the same island (sympatric populations), they tend to exhibit greater differences in morphology (shape of beak) and resource use than when found on different islands (allopatric populations).

Character displacement allows the two species to avoid competition.

It can broadly be classified into

A) **Ecological Character Displacement** and

B) **Reproductive Character Displacement**

Ecological character displacement" refers to trait evolution stemming from selection to lessen resource competition between species and therefore acts on traits associated with resource use (e.g., morphological structures such as beaks and jaws

Reproductive character displacement” refers to trait evolution stemming from selection to lessen sexual interactions between species and therefore acts on traits associated with reproduction (e.g., sexual signals or female mate preferences

Causes of Character displacement: communities or taxa that are more prone to undergo character displacement will likely be more diverse that those communities or taxa where character displacement does not occur, for at least two reasons. First, species that undergo character displacement are less likely to go extinct through competitive or reproductive exclusion. Second, character displacement may promote speciation. Hence, as part of a more general theory for why some communities or taxa are more diverse than others, it is important to determine what factors facilitate character displacement.

Factors that Facilitate Character Displacement

Four, nonexclusive factors appear to facilitate character displacement and therefore make it more likely to unfold. Two are evolutionary factors:

1. Strong selection disfavoring interactions with heterospecifics, and
2. Ecological opportunity.

The remaining two are proximate factors-

3. Initial trait differences between species
4. Abundant standing variation.

Although these factors facilitate adaptive evolution in general, and are therefore not unique to character displacement.

First, character displacement is more likely to occur when selection against interactions with heterospecifics is strong. For example, reproductive character displacement is increasingly likely to occur as the costs of hybridization increase. Moreover, differences between species in the strength of selection to avoid interactions with the other species may explain asymmetric character displacement, where one species diverges less than another species. When one species suffers higher costs in the interaction, it may experience greater divergence than the other species (although asymmetric character displacement can occur for other reasons not described here; Character displacement should also be more likely to occur when the encounter rate between species is high, and, hence, when selection disfavoring interactions with heterospecifics is strong Second, character displacement is facilitated by “ecological opportunity,” the availability of different resource types underutilized by other species although the concept of ecological opportunity has traditionally been applied to resources, a similar principle applies to having available signal space in the case of reproductive character displacement). Character displacement often generates new resource-use or reproductive traits in sympatry that differ from the pre-displacement traits in allopatry Therefore, for character displacement to occur, exploitable resources or signal space that are not already utilized by another species must be available (i.e., there must be resources or signal space onto which a species can actually be displaced; in the absence of exploitable resources or signal space, competitive or reproductive exclusion may result.

Third, character displacement occurs most readily if interacting species already differ in phenotypic traits under selection when they come into contact with one another. Although character displacement can occur without such initial differences, character displacement is facilitated if other factors “jump-start” the divergence, prior to interactions with heterospecifics. Such factors may act in allopatry before the two species come into contact with one another, and they may include drift or spatially divergent natural or sexual selection Such differences may then be amplified in sympatry by selection acting to lessen interspecific interactions In the absence of initial differences between species, one species will be more likely to drive the other locally extinct; e.g., through competitive or reproductive exclusion (see above). Thus, species that differ initially from heterospecifics should be more prone to undergo character displacement.

Finally, character displacement may be more likely to occur when interacting species are phenotypically variable. Phenotypic variation is important, because it increases the chances that character displacement can evolve through the selective filtering of divergent phenotypes in sympatry that were already present in allopatry. Indeed, because this process should unfold relatively rapidly, abundant standing variation should facilitate character displacement as opposed to competitive or reproductive exclusion. Thus, species with abundant standing variation should therefore be especially likely to undergo character displacement.

Given that abundant standing variation might facilitate character displacement, what evolutionary and developmental mechanisms generate such variation?

Answering this question could explain why some populations are predisposed to undergo character displacement. In the next section, we discuss two such mechanisms: intraspecific competition and phenotypic plasticity.

species with abundant standing variation should be especially prone to undergo character displacement. Therefore, identifying the mechanisms that generate and maintain variation within natural populations is crucial for understanding the factors that facilitate character displacement. One such mechanism is disruptive selection, which arises when extreme phenotypes have a fitness advantage over more intermediate phenotypes

Consequences of Character Displacement

character displacement can influence four key evolutionary processes: correlated evolution, sexual selection, speciation, and extinction. By influencing how these processes unfold, character displacement has potentially far reaching impacts beyond mere trait divergence between species.

Speciation

Character displacement potentially plays a critical role in speciation in two ways. First, character displacement can finalize speciation between already divergent groups. Second, character displacement can initiate divergence and reproductive isolation between populations that differ in their interactions with hetero specifics We discuss each of these avenues to speciation in turn.

Character displacement generally promotes species coexistence. Depending on the way that character displacement unfolds, however, it may, counter intuitively, also enhance the risk of extinction in populations that are sympatric with hetero specifics relative to those that are not

Inter specific Interactions and Community Structure

A huge question that has occupied ecologists is the influence of inter specific interactions (competition, predation, mutualism, etc.) on the structure of a community.

One of the most dramatic examples of the interdependence of species and community structure is in the concept of keystone species.

Robert Paine's Experiment

Robert Paine's (University of Washington) famous experiment involved two species of intertidal invertebrate: the sea star, *Pisaster ochraceous*, and the mussel, *Mytilus californicus*.

Normally these two different species live in a harmonious balance in their intertidal community.

The sea star is an important predator: when Paine removed this predator from experimental areas, what had been diverse communities of algae and invertebrates (like what we saw when we snorkeled at Catalina Island), became overgrown with solid stands of the California mussel!

- So, even though the California mussel is a good competitor, its populations had been held in check by sea star predation.
- With the predator gone, the species diversity and structural complexity of the habitat changed radically.

Keystone Species

- A term coined by Paine to indicate a species that has an exceptionally great impact on the surrounding species relative to its abundance.
- Another example: Sea otters are a keystone species. They feed heavily on large herbivorous invertebrates such as sea urchins. When sea otters keep sea urchin populations low, the huge algae (called kelp) can grow more readily and form forests that are home to a diversity of fish and invertebrates. If sea otter populations are reduced, then the near-shore community is overrun with sea urchins and species diversity is reduced

1.7 Summary

After going through this unit you have understood that the concepts of environment and its components and further the interactions among them which bring the adaptations and thus create variations and these variations initiate the origin of newer species. The physical environmental factors influence each other and also have significant impact over the biotic constituents of the environment. The abiotic and biotic interactions create relationships among them and these interactions develop the habitat of the living beings which further directs them for further interactions between them for sharing of the habitat and resources. The concept of habitat and niche are discussed in details and topics such as interaction between physical and biological components are also elaborated. The complex interactions/relationships are explained in simplified forms along with suitable examples.

The understanding of environment is essential for knowledge of comprehensive animal biology.

1.8 Glossary

- **Abiotic factors:** the physical factors of the environment without life
- **Biotic factors:** living components of the environment
- **Inter-specific:** the interaction between the individuals of two or more species
- **Intra-specific:** the interaction between the individuals of a single species
- **Parasite:** the individual living being which feeds upon the other living being causing harm to it.
- **Lineage:** in the same or linear sequence
- **Habitat:** the site where an individual /community live
- **Niche:** is – a specific place of an organism in an ecosystem

1 .9 Self-Learning Excercise

Section -A (Multiple Choice Questions)

1. Which type of soil is best suited for crop production:
   a. Sandy b. Clay
   c. Loam d. Sandy loam
2. Short zone of rapidly falling temperatures in aquatic habitat is known as:
   a. Epilimnion b. Hypolimnion
   c. Thermocline d. Nereitic
3. Lichens are examples of:
   a. Mutualism b. Parasitism
   c. Hyperparasitism d. Competition
4. According to which rule Geographical races of species inhibiting cold regions are much larger as compared to their warmer counterparts:
   a. Jordan's rule b. Bergman's rule
   c. Allen's rule d. Gloger's rule
5. Animals living in caves have:

a. Well developed eyes b. Half developed eyes

c. No or ruminant eyes d. Normal eyes

6. Who coined the term Character displacement:

a. Gause b. Odum

c. Brown and Wilson d. Haeckel

Section -B (Short Answer Type)

1. What is photoperiodism?
2. What is cyclomorphosis?
3. Define ‘Ecological Niche’?
4. What are ‘Ecological Equivalents’?
5. Give examples of Commensalim.
6. What is Jordan’s rule:
7. Explain Gause’s Exclusion principle.
8. What is ‘Field capacity’?
9. Differentiate between symbiosis and commensalism
10. What do you mean by keystone species?

Section -C (Long Answer Type)

1. Discuss soil and water as important abiotic factors.
2. Write an essay on Character displacement and Resource partitioning.
3. Explain positive and negative biotic interactions.
4. Discuss the role of temperature in animal distribution.
5. Discuss in detail the Leibig’s law of minimum and Shelford’s law of tolerance and how can these two be combined?
6. Explain interspecific and intraspecific interactions with examples

1.8 References

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Unit - 2

Population Ecology

Structure of the Unit

2.0 Objectives

After going through this unit you will be able to understand

- About the population ecology.
- Characteristics of population.
- Population growth curves
- Population regulation
- Life history models
- Concept of meta population
- Extinction in metapopulation
- Age structured populations (Leslie matrix)

2.1 Introduction of population ecology

Ecology: Ecology is the interactions among organisms and between the organism and its physical (abiotic) environment. Ecology is basically concerned with four levels of biological organisation – organisms, populations, communities and biomes.

Population: A group of individuals of a single species living in the same general area is called population.

The definition of the population is also given by some scientists:

Cole (1957): A biological unit at the level of ecological integration where it is meaningful to speak of birth rate, death rate, sex ratios, and age structure in describing properties or parameters of the unit.

Krebs (1972): A group of organisms of the same species occupying a particular space at a particular time

Gotelli (1998): A group of plants, animals, or other organisms, all of the same species, that live together and reproduce.

For example: population of human beings in a city, or population lions in a forest.

Population ecology is the study of populations in relation to the environment, including environmental influences on density and distribution, age structure, and population size.

It has almost the same meaning as that of conventional term Autecology (the study of ecology of individual species or its population), which is less in use now.

Population ecology is a significant branch of ecology that plays an important role in protecting and managing populations, especially those of rare species. Each population has a minimum viable size - the size at which it can avoid the extinction due to various biotic and abiotic factors.

Types of populations: Populations are groups of individuals

2.1.1 Unitary Populations

In unitary populations, unitary organisms is usually no problem recognizing individuals, because they are both genetically and physiologically separate. Many species of plants and invertebrates, however, have vegetative propagation to produce new individuals, besides sexual reproduction. Examples include mammals (including humans), birds, amphibians and insects. Each cow has four legs, two eyes, and a tail., i.e., each individual shows a definite shape and size.

2.1.2 Modular Populations

Modular populations are those where an organism develops from a zygote and serves as a unit module and several other modules are produced from it, forming a branching pattern. Examples of modular organisms are plants, sponges, hydroids, fungi, bacteria and corals. Some modular organisms such as trees may grow vertically while others like grasses spread horizontally on the substratum. The structure and pattern of modular organisms is not determinate and thus unpredictable.

2.2 Characteristics of population

Populations are identified by a number of characteristics. These are:

2.2.1 Population density

2.2.2 Natality

2.2.3 Patterns of dispersion

2.2.4 Age structure

2.2.5 Mortality

2.2.6 Population growth and dispersal

2.2.1 Population density

Population size is usually determined on the basis of density, i.e. number of individuals per unit area or per unit volume. For example, 200 trees found in one hectare of land tell us about the density of the tree population.

The population density is often of two types-

2.2.1.1 **Crude density:** Crude density is that density, which takes in account all area of land or aquatic ecosystems under consideration, e.g. number of squirrels in a forest.

2.2.1.2 **Ecological density:** Ecological density on the other hand, takes in account abundance of individuals in the actual area occupied by a population.

The difference in the two types of densities becomes more apparent when the species are clumped together in a small area. However, crude density is studied frequently more than the ecological density because it is very difficult to determine the 'actual area' of inhabitation of a species.

2.2.2 Natality

Natality in population ecology is the scientific term for birth rate. Along with mortality rate, natality rate is used to calculate the dynamics of a population. Natality means production of new individuals (offspring) of an organism in a population. The new individuals can be formed through birth, hatching, and germination. The number of offspring produced per female per unit time is known as **rate of natality.**

Natality can be of two types:

2.2.2.1 Absolute natality: Absolute natality also known as **Fecundity** *rate* means maximum offspring produced under most suitable environmental conditions. This value is theoretical and constant for a given population.

2.2.2.2 Ecological natality: Ecological natality also known as **Fertility** *rate*, on the other hand, refers to the number of offspring produced under prevailing environmental conditions.

2.2.3 Patterns of dispersion

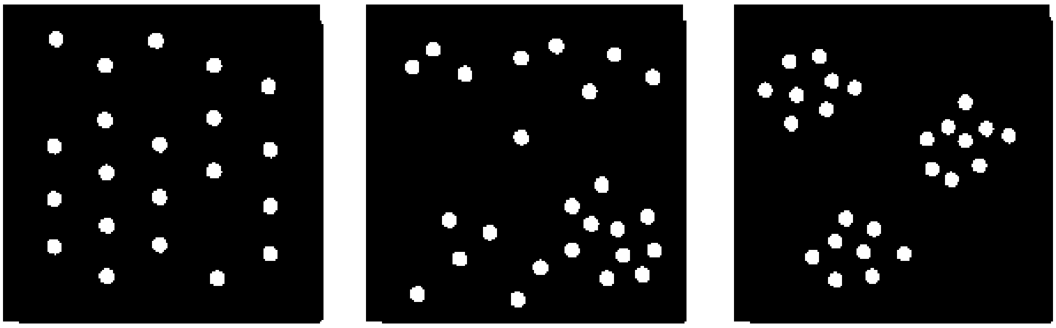
Pattern of dispersion means the manner in which individuals of a population are distributed in space and time. Dispersion may be spatial or temporal. In the latter, example of migratory birds is well- known.

In case of spatial pattern, broadly, three types of dispersion patterns are recognized.

2.2.3.1 Uniform dispersion: In this type, the individuals of a species occur uniformly which is observed in terms of almost equal distances between individuals (Figure 1). This type of dispersion is rare in a natural ecosystem, but common in man-made ecosystems like agro - ecosystems or tree plantations.

2.2.3.2 Random dispersion: In random dispersion, the position of an individual in a population is unrelated to the positions of other individuals (Figure 1). In other words, individuals do not show any systematic pattern of dispersion. This type of dispersion is also rare in nature.

2.2.3.3 Clumped dispersion: In this type of pattern, the individuals of a species are clumped together in space in the form of patches (Figure 1). This type of patchy distribution occurs quite common in nature as individuals of a population occur together because of food availability or better survival rate as in animal populations. In plants, the clumped distribution is very common, and attributed to nutrient availability, specific habitat preference or better environmental conditions.



Uniform Random Clumped

Figure: 1. Different types of dispersion patterns in a population

2.2.4 Age structure

A population is comprised of individuals of different age groups that constitute its age structure. Age structure of a population thus derives from the proportion of individuals in different age groups.

For the sake of convenience, the age categories have been divided into three major stages, **Pre-reproductive**, **Reproductive** and **Post-reproductive**. The proportion of different stages in a population is presented graphically in the form of age pyramid (Figure 2).

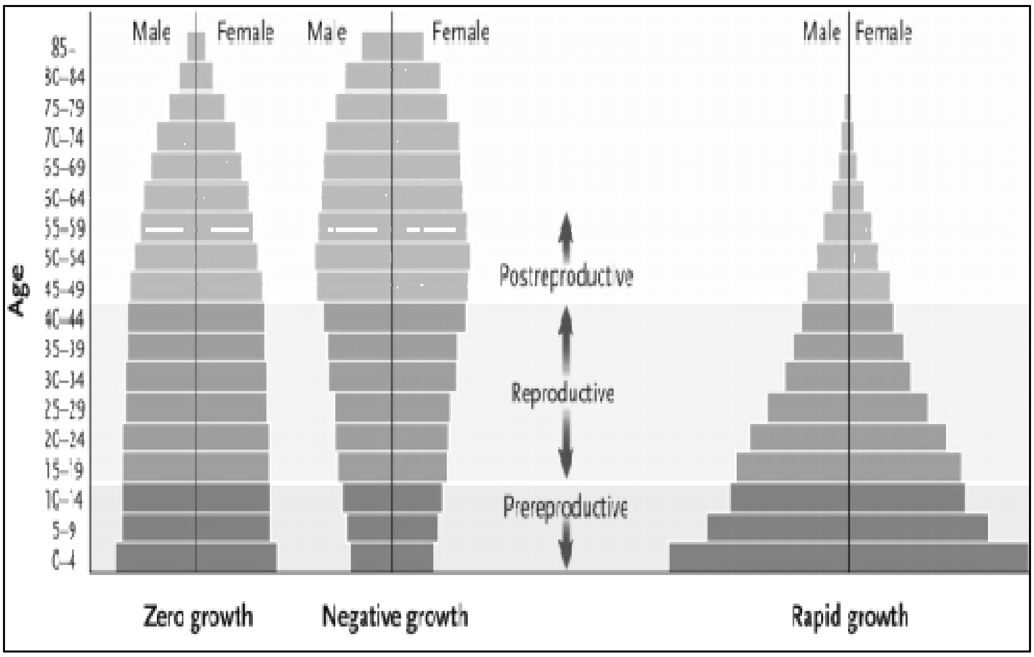


Figure: 2. Hypothetical age distributions for populations with different growth rates

2.2.5 Mortality

Mortality refers to number of deaths per unit population per unit time, e.g., per one thousand individuals per year in humans.

Rate of death of individuals referred to as Mortality rate is of two types:

2.2.5.1 Minimum mortality rate: Minimum mortality *rate*, or also known as **physiological longevity**, refers to the theoretical minimum death rate which occurs under ideal conditions of environment with minimum limiting factors. This value is a theoretical value and constant for a given population

2.2.5.2 Ecological mortality rate: Under actual environmental conditions, the death rate may be more and this actual death rate is referred to as **Ecological mortality**.

2.2.6 Population growth and dispersal

Individuals of a population keep migrating out (Emigration) or into populations (Immigration). Thus, population size and density keep changing with time. In addition, birth and death of individuals also change population size. Immigration and birth increase population size whereas emigration and death decrease its size. Thus, in a given population if birth + immigration > emigration + death, the size of population would increase. On the other hand, if the birth + immigration < emigration + death, then the size of the population would decrease (Figure 3).

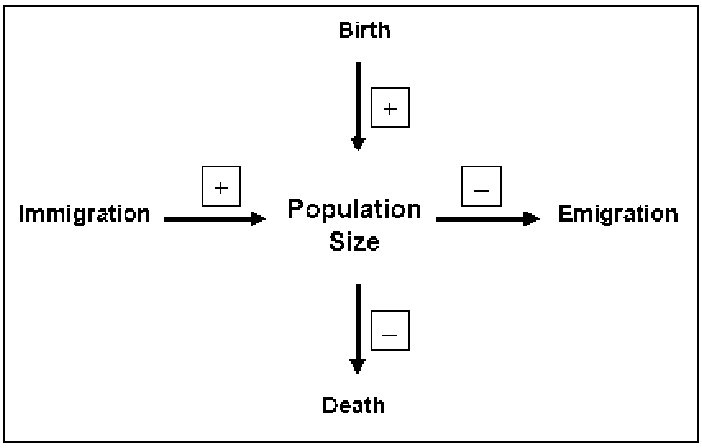


Figure: 3. Influence of immigration, emigration, death rate and birth rate on population size

2.3 Population growth curves

A population is the changing entity. Populations are never static and keep changing in time and space. These changes in population size over time show varied trends.

The term population growth refers to the change in the number of individuals in a population with time. Change in population determined by four factors: birth, death, immigrants and emigrants. Population growth can be exponential growth or logistic growth. In the simplest case of population there is no limitation on growth.

When the environment is unlimited the specific growth rate of populations becomes maximum and constant under a set of environmental conditions. On the other hand, if the food supply or other resources are limited, the growth rate is typically sigmoid, i.e. increases slowly in the beginning followed by rapid increase and then becomes constant as it approaches the upper limit.

To address these growth patterns, there are two types of growth models:

2.3.1 Exponential Growth Model

It is also called J curve or J-shaped growth model. In exponential growth type population increases geometrically or exponentially until there is resource limitation or population growth is limited by other factors. Growth then declines rapidly until the favorable period is restored. Mathematically, this growth model can be expressed as the rate of population increase with time t, *i.e.*

$$\frac{dN}{dt} = rN$$

Where N = population size,

t = time, and

r = intrinsic rate of natural increase. It is described as the maximum potential of reproduction in an individual in particular set of conditions.

The population size that increases exponentially at a constant rate, resulting eventually in J-shaped growth curve when population size is plotted over time. The value of r is the maximum when resources are not limiting. Since the curve drawn between population size (Y-axis) and time (X-axis) is **J-shaped**,

(Figure 4).

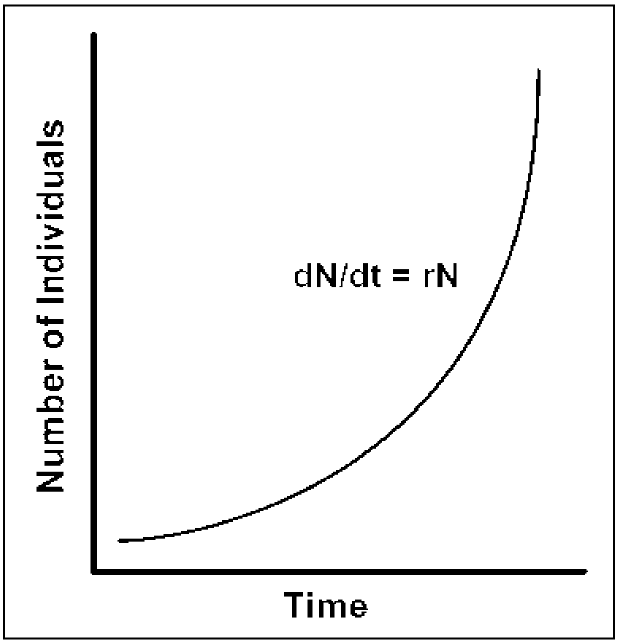


Figure: 4. Population Growth Model: Exponential growth model or J-shaped curve model

2.3.2 Logistic Growth Model

This growth model is also known as S-shaped or Sigmoid growth model. When population growth occurs at a place where resources are limited, it attains a sigmoid or S-shaped curve showing minimum death during early stages. The population increases in size until it reaches an upper limit. This upper limit is known as the Carrying capacity, which is denoted by 'K'. Carrying capacity thus may be defined as capacity of an ecosystem to support maximum number of individuals of a species. As the population size increases, population growth rate declines as it approaches carrying capacity.

Logistic growth is thus density dependent and can be expressed by the following equation:

$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

Where N = population size,

dN/dt = Change in population size per unit time.

r = Intrinsic rate of natural increase

K = carrying capacity.

When N equals K, the growth rate becomes zero and the population reaches equilibrium (Figure: 5).

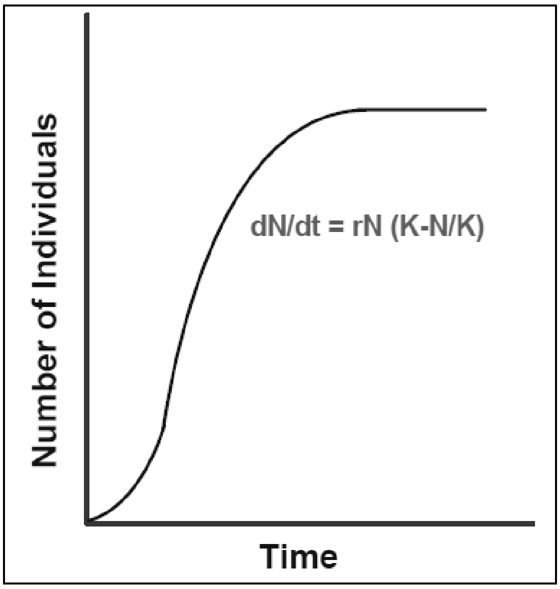


Figure: 5. Population Growth Model: Logistic Growth Model or Sigmoidal or *S*-shaped model

2.4 Population regulation

A number of factors like availability of food, space, water, and pests may regulate population size.

In general, the factors responsible for population regulation can be

2.4.1 density dependent (competition, predation, parasitism, disease outbreak, or herbivory) or

2.4.2 density independent (environmental factors). In density dependent factors, competition (particularly intra-specific i.e. between individuals of same species) plays a major role in limiting population size. Among the density independent factors, floods, fire and other natural calamities remove large proportion of the populations and thus decrease their density.

Sometimes individuals of a population release toxic substances in the soil or water, which tend to limit the growth of their own type of plants (*consepecifics*) and thus control over-crowding of a species at a particular place. This is known as **autoallelopathy or autotoxicity -** a type of interaction where one species releases toxic substances into environment that are detrimental to individualists own growth. Autotoxicity is well demonstrated in a number of food plants like alfalfa (*Medicago sativa*), figs (*Ficus* sps.), grape (*Vitis vinifera*) and peach (*Prunus persica*) orchards; in aquatic and wetland plants like *Typha, Phragmites, Juncus* and algae; and in forest tree or shrub species like *Casuarina*, Walnut (*Juglans* sps.), Coffee (*Coffea arabica*) and tea (*Camellia sinensis*),

2.5 Life history strategies

Life history theories attempt to explain the evolution of organism traits as adaptations to environmental variation. Ecological interest recently has focused on the allocation of resources between competitive and reproductive functions. Much of this interest can be traced to r- and K selection theory. The theory of r- and K-selection was one of the first predictive models for life-history evolution. The theory of r- and K-selection was proposed and popularized by MacArthur and his colleagues in the 1960s and early 1970.

In r/K selection theory, selective pressures are hypothesized to drive evolution in one of two generalized directions: r- or K-selection. These terms, r and K, are drawn from standard ecological algebra as illustrated in the simplified Verhulst model of population dynamics:

$$\frac{dN}{dt} = r\,N\left(1 - \frac{N}{K}\right)$$

where r is the maximum growth rate of the population (N),

K is the carrying capacity of its local environmental setting,

and the notation dN/dt stands for the derivative of N with respect to t (time).

Thus, the equation relates the rate of change of the population N to the current population size and expresses the effect of the two parameters. In the etymology of the Verhulst equation, r comes from rate while K comes from carrying capacity.

2.5.1 r-selection

As the name implies, r-selected species are those that place an emphasis on a high growth rate, and, typically exploit less-crowded ecological niches, and produce many offspring, each of which has a relatively low probability of surviving to adulthood (i.e., high r, low K). A typical r species is the dandelion Taraxacum genus.

In unstable or unpredictable environments, r-selection predominates as the ability to reproduce quickly is crucial. There is little advantage in adaptations that permit successful competition with other organisms, because the environment is likely to change again. Among the traits that are thought to characterize r-selection are high fecundity, small body size, early maturity onset, short generation time, and the ability to disperse offspring widely.

Organisms whose life history is subject to r-selection are often referred to as r-strategists or r-selected. Organisms that exhibit r-selected traits can range from bacteria and diatoms, to insects and grasses, to various semelparous cephalopods and mammals, particularly small rodents.

2.5.2 K-selection

By contrast, K-selected species display traits associated with living at densities close to carrying capacity, and typically are strong competitors in such crowded niches that invest more heavily in fewer offspring, each of which has a relatively high probability of surviving to adulthood (i.e., low r, high K). In scientific literature, r-selected species are occasionally referred to as "opportunistic" whereas K-selected species are described as "equilibrium". A typical K reproducer is the orchid, or members of the Orchis genus.

In stable or predictable environments, K-selection predominates as the ability to compete successfully for limited resources is crucial and populations of K-selected organisms typically are very constant in number and close to the maximum that the environment can bear (unlike r-selected populations, where population sizes can change much more rapidly).

Traits that are thought to be characteristic of K-selection include large body size, long life expectancy, and the production of fewer offspring, which often require extensive parental care until they mature. Organisms whose life history is subject to K-selection are often referred to as K-strategists or K-selected. Organisms with K-selected traits include large organisms such as elephants, humans and whales, but also smaller, long-lived organisms such as Arctic terns.

Table: 1. Correlates of r- and K- selection

Trait	*r*-selection	*K*-Selection
Climate	Variable or unpredictable	Predictable, Less variable
Mortality	Density independent	Density dependent
Survivorship	Type 3	Type 1 or 2
Population size	Variable, below K Recolonization common	Fairly constant, at or near K Recolonization uncommon
Competitive ability	Usually poor	Usually keen
Investment in defence	Little energetic investment	Great energetic investment
Parental care	Minimal	Usually great
Length of life	Short	Long
Stage of succession	Early	Late
Rate of development	Rapid	Slow
r_{max}	High	Low
Prereproductive period	Short	Long
Body size	Small	Large
Number of offspring	Many	Few
Size of offspring	Small	Large
Dispersal ability	Excellent	Fair to poor

2.6 Concept of metapopulation

The metapopulation approach begins by stressing that local populations are influenced by immigration/emigration and extinction, as well as by birth and death processes. Until the 1960s, the idea that populations might routinely go locally extinct was rarely discussed in the literature. However, the population geneticist Sewall Wright (1940), as well as ecologists such as Andrewartha and Birch (1954), introduced the notions that populations are connected by migration and that local extinctions might be commonplace (Hanski 1999). The importance of immigration and emigration to the long-term persistence of a local population, however, was first emphasized by Levins (1970), who coined the term metapopulation. For Levins a metapopulation was a population consisting of many local populations. He asserted that all local populations have a finite probability of extinction, and long-term survival of a species was at the regional or metapopulation level (Hanski 1999). Beginning in the 1990s, as it became obvious that the natural world was becoming increasingly fragmented, the metapopulation approach became standard in the world of conservation biology. An understanding of metapopulations, the probabilities of local extinctions in different-sized natural reserves, and the rates of immigration and emigration between these preserves, became one of the fastest-growing research areas in population, community, landscape, and conservation biology. As currently defined,

metapopulations are regional assemblages of plant and animal species, with the long-term survival of the species depending on a shifting balance between local extinctions and re-colonizations in the patchwork of fragmented landscapes.

The term “metapopulation” has been used for any spatially structured population and “metapopulation dynamics” has been used to refer to any population dynamics involving spatial patterns (Hanski 1998). Furthermore, as Harrison (1994) has pointed out, several different types of metapopulations exist: classical metapopulations, mainland–island metapopulations, non-equilibrium metapopulations, and patchy metapopulations.

The Levins or classical metapopulation

According to the Levins model, metapopulation persistence is due to a stochastic balance between local extinction and re-colonization of empty habitat patches. The rate of change in occupied habitat patches is a function of colonization rates (c) and extinction rates (ε) as shown in Equation 5.2 (Levins

1969). P is the proportion of patches occupied by the population under consideration.

$$\frac{dP}{dt} = cP(1 - P) - \varepsilon P \quad \ldots\ldots\ldots\ldots\ldots\ldots (5.2)$$

As described by Hanski (2001), if we define P′ as the number of habitat fragments occupied by the species (rather than the proportion), and define T as the total number of habitat patches available, the equation can be modified as follows:

$$\frac{dP'}{dt} = cP'(T - P') - \varepsilon P \quad \ldots\ldots\ldots\ldots\ldots\ldots (5.3)$$

Both of these models are deterministic descriptions of the rate of change of metapopulation size, even though the models are based on stochastic events. Assumptions include:

1. The local populations are identical and have the same behavior;
2. extinctions occur independently in different patches and therefore local dynamics are asynchronous;
3. Colonization spreads across the entire patch network and all patches are equally likely to be "encountered;"
4. Furthermore, all patches are equally connected to all other patches.

In the Levins model we are not concerned with population dynamics within each population. We do not attempt to assess the number of individuals in each patch; we simply record a patch as occupied or not occupied. For this reason we also do not assess the size or quality of the patches.

The equilibrium value of P can be obtained by setting dP/dt = 0. This produces the expected proportion of patches to be occupied and amounts to a carrying-capacity term such as is found in the logistic equation.

$$0 = cP(1 - P) - \varepsilon P = P(c - cP - \varepsilon)$$

Since *P* = 0 is not an interesting solution, we have:

$$0 = c - cP - \varepsilon, \qquad and \quad \varepsilon = c - cP$$

The equilibrium value of *P*, defined as *P*ˆ and found by solving the above for *P*, is shown in Equation 5.4:

$$P' = \frac{C - \varepsilon}{C} = 1 - \frac{\varepsilon}{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.4)$$

The implication here is that colonization must be greater than extinction or the equilibrium proportion of patches occupied will be zero, and the colonization rate must be greater than the extinction rate for persistence of the metapopulation. If we consider colonization a "birth" event and extinction a "death" event (thereby using c − ε as the equivalent of the growth rate, r, in the logistic equation) and we use 1 − ε /c to represent

a "carrying capacity" term (equivalent to K in the logistic equation) as mentioned above, we can model metapopulation dynamics as a modification of the logistic (Equation 5.5).

No matter what the starting patch frequency is (assuming 1 ≥ P > 0), over time it moves to the expected value based on P ˆ = 1 − ε /c (see Figure 6).

$$\frac{dP}{dt} = (c - \varepsilon)\ P\left(1 - \frac{P}{1 - \varepsilon/c}\right) \qquad (5.5)$$

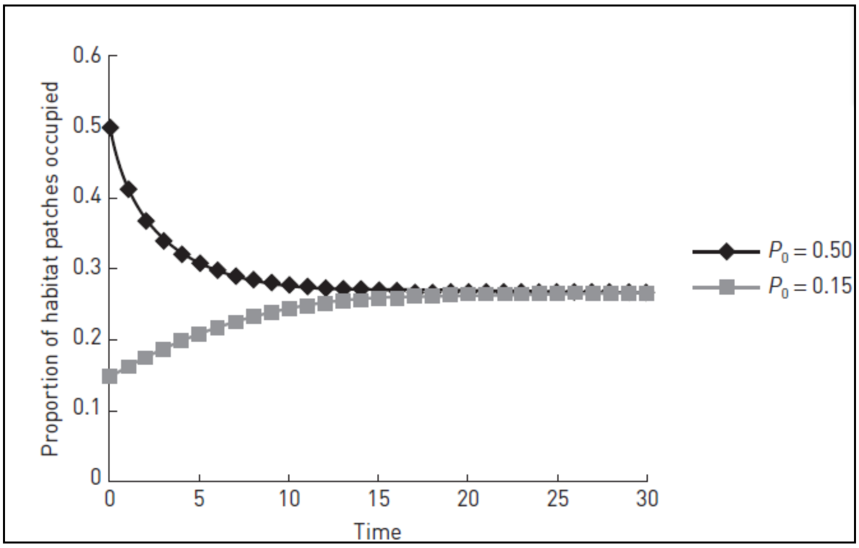


Figure: 6. Expected proportion of habitat patches occupied, based on Equation 5.5. In this example P0 = 0.50 and 0.15, the colonization rate c = 0.75, and the extinction rate e = 0.55. The expected proportion of patches occupied at equilibrium = 1 − e/c = 0.27.

2.7 Extinction in metapopulation

In metapopulation dynamics, as well as in the MacArthur and Wilson theory, the extinction of a local population is not uncommon. But we are more interested here in the extinction of the metapopulation. Table 2 summarizes the potential causes of both local and metapopulation extinctions.

Table: 2. Potential causes of local and metapopulation extinctions

	Local extinction	Metapopulation extinction
Stochastic processes	(a) Demographic	(a) Extinction–colonization interaction
	(b) Environmental	(b) Regional processes
Extrinsic causes	Habitat loss	Habitat loss and fragmentation

We need only comment on the comparison of stochastic processes in local versus metapopulation extinctions. One of the assumptions for long-term metapopulation persistence is that the expected number of new populations generated by one existing population during its lifetime must be greater than one. That is, the replacement rate must be greater than one, as is true for a local population to persist. In a small metapopulation, however, all local populations may go extinct by chance. This is known as "extinction–colonization stochasticity". This is an exact analogue to demographic, stochastic extinction of a local population. This may happen even if the replacement rate is greater than one in both local populations and metapopulations. Regional stochasticity is due to processes such as large-scale weather patterns, which produce synchrony among the independent local populations. This effectively reduces the number of independent populations and makes metapopulation-level persistence less likely.

2.8 Age structured populations (Leslie matrix)

Leslie matrix is a discrete, age structured model of population growth that is very popular in population ecology. It was invented by and named after P. H. Leslie. The Leslie Matrix (also called the Leslie Model) is one of the best known ways to describe the growth of populations (and their projected age distribution), in which a population is closed to migration and where only one sex, usually the female, is considered. This is also used to model the changes in a population of organisms over a period of time. Leslie matrix is generally applied to populations with annual breeding cycle. In a Leslie Model, the population is divided into groups based on age classes. A similar model which replaces age classes with life stage is called a Lefkovitch matrix, whereby individuals can both remain in the same stage class or move on to the next one. At each time step the population is represented by a vector with an element for each age classes where each element indicates the number of individuals currently in that class. The Leslie Matrix is a square matrix with the same number of rows and columns and the population vector as elements.

The matrix approach allows quick calculations of changes in the age structure and total population size as well as a quick method for finding λ when there is a stable age distribution. The survivorship and fertility columns are placed in matrix form |A|. The population itself is considered a column vector which, when multiplied by the matrix, produces a new column vector representing the population at time t + 1:

$$N_{t+1} = |A| N_t$$

Table: 3. General matrix format for projecting a population with five age classes for one time period (t = 0 to t = 1).

Age classes	*Matrix*						*t* = 0		*t* = 1
0	p_0m_1	p_1m_2	p_2m_3	p_3m_4	0		n_0		n_0
1	p_0	0	0	0	0		n_1		n_1
2	0	p_1	0	0	0	×	n_2	=	n_2
3	0	0	p_2	0	0		n_3		n_3
4	0	0	0	p_3	0		n_4		n_4

For age class 0 the number of individuals is based on: $p_0m_1n_0 + p_1m_2n_1 + p_2m_3n_2 + p_3m_4n_3 + 0$.

For age class 1 the number of individuals is calculated as: $p_0n_0 + 0 + 0 + 0 + 0$.

For age class 2 the number of individuals is calculated as: $0 + p_1n_1 + 0 + 0 + 0$.

For age class 3 the number of individuals is calculated as: $0 + 0 + p_2n_2 + 0 + 0$.

For age class 4 the number of individuals is calculated as: $0 + 0 + 0 + p_3n_3 + 0$.

The format for the matrix is as shown in Table 3. The *px* values (the probabilities of surviving from age *x* to age *x* + 1) appear in the matrix in the off diagonal. The first row consists of the products $p_x \times m_{x+1}$. The matrix must be a square matrix, with the final column consisting of zeros. In this example, with five age classes, we have a 5 × 5 matrix. Given the rules of matrix multiplication, the product of the matrix times the column vector (representing the population by age classes at $t = 0$) results in a column vector at time $t = 1$.

Advantages and Disadvantages of Leslie Matrices:

Advantages:

1. Stable age distribution is not required for valid population projections.
2. Can conduct sensitivity analysis to see how changing certain age specific vital rates affects population size and age structure.
3. Can incorporate density dependence, i.e., can dampen values in the matrix to account for density dependent factors limiting population growth.
4. Can derive useful mathematical properties from the matrix formulas, including stable age distribution and finite rate of population change (i.e., lambda).

Disadvantages:

1. Requires a large amount of data (i.e., age specific data on survival, fecundity, and population structure).
2. In practice, the estimation of Fx is difficult at best.

2.9 Glossary

- **Population Ecology =** the study of how populations interact with their environment
- **Population =** group of individuals of the same species occupying a common geographical area
- **Population size =** number of individuals making up its gene pool
- **Population density =** number of individuals per unit of area or volume, e.g. • persons/square mile
- **Age structure =** Age structure defines the relative proportions of individuals of each age: Pre-reproductive, Reproductive, and Post-reproductive
- **r-selected organisms** = put most of their energy into rapid growth and reproduction. This is common of organisms that occupy unpredictable environments, e.g. weeds are usually annuals with rapid growth and early reproduction. They produce a large number of seeds containing few stored nutrients

- **K-selected organisms** = put most of their energy into growth. They are common in stable environments near carrying capacity, e.g. long lived trees such as redwoods take many years of growth to reach reproductive age
- **Metapopulation =** A set of spatially disjunct populations, among which there is some immigration.

2.10 Self-learning exercise

Section -A (Very Short Answer Type)

1. A group of individuals of a single species living in the same general area is called __________________
2. Ecology is the interactions among ______________
3. Mortality refers to ___________ of ____________ in a population.
4. The theory of r- and K-selection was proposed and popularized by __________________
5. Leslie matrix is invented by ____________

Section -B (Short Answer Type)

1. Explain the types of populations?
2. Explain the population density with their types?
3. A Short note on natality?
4. Explain Population growth and dispersal?
5. What are the patterns of dispersion?
6. A Short note on difference in exponential and logistic growth curves?
7. Differentiate and correlates of r- and K- selection?
8. What is population regulation?

Section -C (Long Answer Type)

1. Explain the life history strategies?
2. Write about the population growth curves?
3. Describe the concept of metapopulation?
4. Briefly describe the age structured populations (Leslie matrix) with their advantages and disadvantages?

2.11 References

- Introduction to Population Ecology by Larry L. Rockwood
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Unit -3

Species Interactions and Community Ecology

Structure of the Unit

3.1 Types of Interactions

Ecology is a branch of science that deals with the study of distribution and abundance of organisms in the ecosystem, and their interactions with the environments. The environments include both abiotic (physical) and biotic (biological) factors. The physical factors may be divided into those which plants and animals use as resources, such as the nutrients in the soil, CO_2, water and the critical factors for their survival such as temperature, wind, pH and osmotic balances. The physical environment commonly limits population abundance of plants and animals, as well as their geographic distributions. It can also change the species composition that occurs in the ecosystem. On the other hand, biotic ecosystem includes organisms, organic molecules, and cells and is a most diverse and easily changeable part of ecosystems. Since all living things in an ecosystem are interdependent, the associations existing between the different organisms in the ecosystem influences the survival of organisms and the functioning of the ecosystem as a whole. Hence to understand the overall dynamics of the ecosystem, it is important to consider the impact of both environmental variations and multispecies interactions, which will have both ecological and evolutionary effects.

In ecology, biological interactions can involve individuals of the same species (intraspecific interactions) or individuals of different species (interspecific interactions). These can be further classified by either the mechanism of the interaction or the strength, duration and direction of their effects. Species may interact once in a generation (e.g. pollination) or live completely within another (e.g. endosymbiosis). Effects range from consumption of another individual (predation,herbivory, or cannibalism), to mutual benefit (mutualism). Interactions need not be direct; individuals may affect each other indirectly through intermediaries such as shared resources or common enemies.

3.2 Inter Specific Interactions in the Ecosystem

In addition to the abiotic factors on the environment, the populations can be very much affected by the interactions between the organisms in the ecosystem. The “species interactions” explains most of the domain of ecology. The major types of interactions are discussed below:

1. Competition

The process competition is thought to be a part of daily life. Competition is a relationship in which different organisms or populations in the ecosystem attempt to use the same limited resources at the same time. The limiting resource may be water, prey, light, water etc, which is responsible for the organism’s growth and survival in the ecosystem. Competition can occur both within (intra specific) and between (**inter specific**) species. An individual experiences both types of competition, but the range of the competitions varies widely from population to population and species to species. Competition among the individuals can also be characterized as resource competition or interference competition. The resource **competition** is characterized by the organism’s completion directly for the limiting nutrient in the ecosystem, there by obtaining as much each individual can. An example is the competition of fly maggots in a mouse carcass, where few individuals obtain enough nutrients for their reproduction and survival. Resource **competition** may not always cause the exclusion of one species instead some species can coexist, with a marked reduction in their growth potential capabilities. In **interference competition**, the individuals harm each other directly by a physical force. In this case either the individuals interact with foraging, survival, and reproduction of others or directly prevent their physical organization in a part of their habitat. An example is the physical intimidates of caterpillar to other. Interference competition generally results in the exclusion of one of the two competitors.

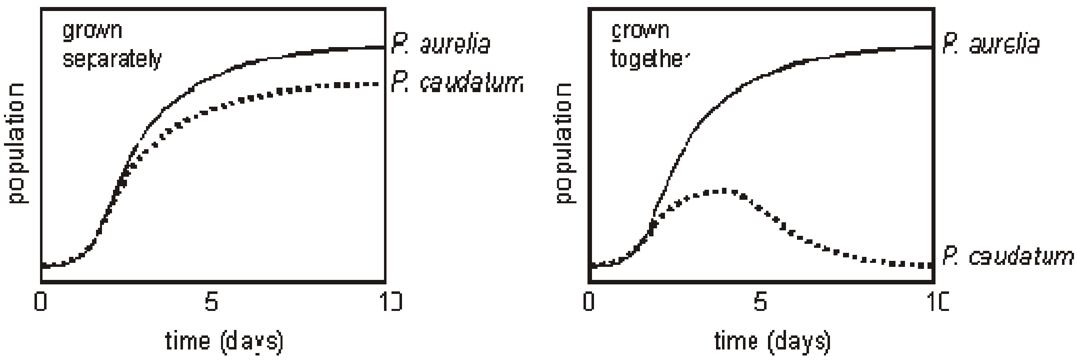
Early in the 20th Century, A.J. Lotka and V. Volterra developed a model for population growth, which explains that two species cannot compete for the same limiting resource for a long period. This is known as **Competitive exclusion principle**. **G.F.Gausse**, a Russian ecologist, demonstrated that *Paramecium aurellia* competes and later displaces *Paramecium caudatum* which apparently confirmed the Competitive exclusion theory. Recent studies showed the coexistence of some killer particle in Gausse's strain *P. aurellia* is responsible for such an outcome. Later Thomas Park showed that due to interference competition, the confused flour beetle and the red flower beetle would not coexist and hence one species always excluded the other.

Competition among members of the same species is known as intraspecific competition, while competition between individuals of different species is known as interspecific competition.

Interspecific competition is normally not as fierce as intraspecific competition, unless in case of a sudden drastic change. However, it is the most conspicuous competition in grasslands, where, for example, cheetahs and hyenas are often killed by lion prides. Competition is not always a straightforward, direct interaction either, and can occur in both a direct and indirect fashion.

(a) Interspecific Competition

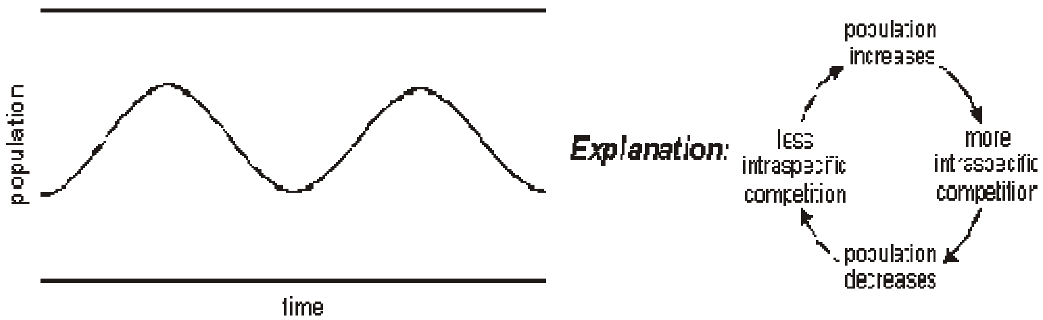
Interspecific competition is competition for resources (such as food, space, water, light, etc.) between members of different species, and in general one species will out-compete another one. This can be demonstrated by growing two different species of the protozoan *Paramecium* in flasks in a lab. They both grow well in lab flasks when grown separately, but when grown together *P.aurelia* out-competes *P.caudatum* for food, so the population of *P.caudatum* falls due to interspecific competition:



(b) Intraspecific Competition

Intraspecific competition is competition for resources between members of the same species. This is more significant than interspecific competition, since member of the same species have the same niche and so compete for exactly the same resources.

Intraspecific competition tends to have a stabilising influence on population size. If the population gets too big, intraspecific population increases, so the population falls again. If the population gets too small, intraspecific population decreases, so the population increases again:



Intraspecific competition is also the driving force behind natural selection, since the individuals with the "best" genes are more likely to win the competition and pass on their genes. Some species use aggressive behaviour to minimise real competition. Ritual fights, displays, threat postures are used to allow some individuals (the "best") to reproduce and exclude others (the "weakest"). This avoids real fights or shortages, and results in an optimum size for a population.

Competition between species at the same trophic level of an ecosystem, who have common predators, increases drastically if the frequency of the common predator in the community is decreased by a large margin. The magnitude of competition therefore depends on many factors in the same ecosystem.

According to the competitive exclusion principle, species less suited to compete for resources should either adapt or die out. According to evolutionary theory, this competition within and between species for resources plays a critical role in natural selection.

2. Amensalism

Amensalism is an interaction where an organism inflicts harm to another organism without any costs or benefits received by itself. A clear case of amensalism is where sheep or cattle trample grass. Whilst the presence of the grass causes negligible detrimental effects to the animal's hoof, the grass suffers from being crushed. **Amensalism** is often used to describe strongly **asymmetrical competitive interactions**, such as has been observed between the Spanish ibex and weevils of the genus *Timarcha* which feed upon the same type of shrub. Whilst the presence of the weevil has almost no influence on food availability, the presence of ibex has an enormous detrimental effect on weevil numbers, as they consume significant quantities of plant matter and incidentally ingest the weevils upon it.

3. Antagonism

In antagonistic interactions, one species benefits at the expense of another. Predation is an interaction between organisms in which one organism captures biomass from another. It is often used as a synonym for carnivory but in its widest definition includes all forms of one organism eating another, regardless of trophic level (e.g., herbivory), closeness of association (e.g., parasitism and parasitoidism) and harm done to prey (e.g., grazing). Intraguild predation occurs when an organism preys upon another of different species but at the same trophic level (e.g., coyotes kill and ingest gray foxes in southern California). **Batesian mimicry** is also an antagonistic interaction, where one species has evolved to mimic another, to the advantage of the copying species but to the detriment of the species being mimicked.

4. Neutralism

Neutralism describes the relationship between two species that interact but do not affect each other. It describes interactions where the health of one species has absolutely no effect whatsoever on that of the other. Examples of true neutralism are virtually impossible to prove and most ecologists (as well as textbooks) would agree that this concept does not exist. When dealing with the complex networks of interactions presented by ecosystems, one cannot assert positively that there is absolutely no competition between or benefit to either species. However, the term is often used to describe situations where interactions are negligible or insignificant.

5. Commensalism

Commensalism benefits one organism and the other organism is neither benefited nor harmed. It occurs when one organism takes benefits by interacting with another organism by which the host organism is not affected. A good example is a *Remora* living with a shark. *Remora* eat left over food from the shark. The shark is not affected in the process, as *Remora* eat only left over food of the shark, which does not deplete the shark's resources.

Commensal interactions are difficult to document in nature because any close association between species likely affects both species, if only slightly.

For example, “hitchhiking” species, such as the barnacles that attach to whales, are sometimes considered commensal. The hitchhiking barnacles gain access to a substrate and seem to have little effect on the whale. However, the barnacles may slightly reduce the host’s efficiency of movement. Conversely, they may provide some camouflage.

When commensalism may not be commensalism ?

One of the best-known examples of symbiosis involves the relationships between certain small tropical fishes (clownfish) and sea anemones. The fish have evolved the ability to live among the stinging tentacles of sea anemones, even though these tentacles would quickly paralyze other fishes that touched them. The clownfish feed on food particles left from the meals of the host anemone, remaining uninjured under remarkable circumstances.

On land, an analogous relationship exists between birds called oxpeckers and grazing animals such as cattle or antelopes. The birds spend most of their time clinging to the animals, picking off parasites and other insects, carrying out their entire life cycles in close association with the host animals.

No clear-cut boundary exists between commensalism and mutualism; in each of these instances, it is difficult to be certain whether the second partner receives a benefit or not. It may be advantageous to the sea anemone to have particles of food removed from its tentacles because it may then be better able to catch other prey. Similarly, while often thought of as commensalism, the association of grazing mammals and gleaning birds is actually an example of mutualism. The mammal benefits by having parasites and other insects removed from its body, but the birds also benefit by gaining a dependable source of food.

On the other hand, commensalism can easily transform itself into parasitism. Oxpeckers are also known to pick not only parasites, but also scabs off their grazing hosts. Once the scab is picked, the birds drink the blood that flows from the wound. Occasionally, the cumulative effect of persistent attacks can greatly weaken the herbivore, particularly when conditions are not favorable, such as during droughts.

6. Mutualism

Unlike commensalism, mutualism is an interspecific interaction between two organisms in the ecosystem with benefit to both the associating members in the interaction. During this interaction, populations of each interacting species grow survive and reproduce at a higher rate in the presence of the other interacting species. Pollination is a good example to explain mutualism, where the plant gets benefit from the dispersal of pollen the pollinator obtaining a meal of nectar from the flower. Mutualism is an interaction between two or more species, where species derive a mutual benefit, for example an increased carrying capacity. Similar interactions within a species are known as co-operation. Mutualism may be classified in terms of the closeness of association, the closest being symbiosis, which is often confused with mutualism. One or both species involved in the interaction may be obligate, meaning they cannot survive in the short or long term without the other species. Though mutualism has historically received less attention than other interactions such as predation, it is very important subject in ecology. Examples includecleaner fish, pollination and seed dispersal, gut flora,Müllerian mimicry. Mutualism is an interspecific symbiosis in which two species benefit from their interaction (+/+).

Examples of mutualism include nitrogen fixation by bacteria in the root nodules of legumes; digestion of cellulose by **microorganisms** in the guts of **ruminant** mammals; and the exchange of nutrients in *Mycorrhizae*, the association of **fungi** and plant roots. Mutualistic interactions may result in the evolution of related adaptations in both species. Commensalism is an interaction that benefits one species but neither harms nor helps the other (+/0). Pollination illustrates mutualism between flowering plants and their animal pollinators.

Mutualism and coevolution

Some of the most spectacular examples of mutualism occur among flowering plants and their animal visitors, including insects, birds, and bats. During the course of flowering-plant evolution, the characteristics of flowers evolved in relation to the characteristics of the animals that visit them for food and, in the process, spread their pollen from individual to individual. At the same time, characteristics of the animals have changed, increasing their specialization for obtaining food or other substances from particular kinds of flowers.

Another example of mutualism involves ants and aphids. Aphids are small insects that suck fluids from the phloem of living plants with their piercing mouthparts. They extract a certain amount of the sucrose and other nutrients from this fluid, but they excrete much of it in an altered form through their anus. Certain ants have taken advantage of this in effect, domesticating the aphids. The ants carry the aphids to new plants, where they come into contact with new sources of food, and then consume as food the "honeydew" that the aphids excrete.

When mutualism may not be mutualism

As with commensalism, however, things are not always as they seem. Ant–acacia associations also occur in Africa; in Kenya, several species of acacia ants occur, but only a single species is found on any one tree. One species, *Crematogaster nigriceps,* is competitively inferior to two of the other species. To prevent invasion by these other ant species*, C. nigriceps* prunes the branches of the acacia, preventing it from coming into contact with branches of other trees, which would serve as a bridge for invaders.

Although this behavior is beneficial to the ant, it is detrimental to the tree because it destroys the tissue from which flowers are produced, essentially sterilizing the tree. In this case, what initially evolved as a mutualistic interaction has instead become a parasitic one.

7. Parasitism

Parasitism benefits one species at the expense of another

Parasitism may be regarded as a special form of symbiosis in which the parasite usually is much smaller than the prey and remains closely associated with it. Parasitism is harmful to the prey organism and beneficial to the parasite. In many cases, the parasite kills its host, and thus the ecological effects of parasitism can be similar to those of predation. Although in the past parasitism was usually studied mostly in terms of its effects on individuals and the populations in which they live, in recent years researchers have realized that parasitism can be an important factor affecting the structure of communities.

(a) External parasites

Parasites that feed on the exterior surface of an organism are external parasites, or ectoparasites. Many instances of external parasitism are known in both plants and animals. Parasitoids are insects that lay eggs on living hosts. This behavior is common among wasps, whose larvae feed on the body of the unfortunate host, often killing it.

(b) Internal parasites

Parasites that live within the body of their hosts, termed endoparasites, occur in many different phyla of animals and protists. Internal parasitism is generally marked by much more extreme specialization than external parasitism, as shown by the many protist and invertebrate parasites that infect humans.

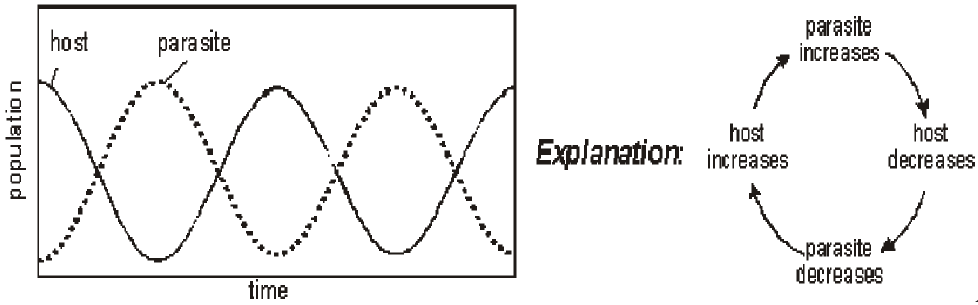
The more closely the life of the parasite is linked with that of its host, the more its morphology and behavior are likely to have been modified during the course of its evolution (the same is true of symbiotic relationships of all sorts). Conditions within the body of an organism are different from those encountered outside and are apt to be much more constant. Consequently, the structure of an internal parasite is often simplified, and unnecessary armaments and structures are lost as it evolves.

(c) Parasites and host behaviors

Many parasites have complex life cycles that require several different hosts for growth to adulthood and reproduction. Recent research has revealed the remarkable adaptations of certain parasites that alter the behavior of the host and thus facilitate transmission from one host to the next. For example, many parasites cause their hosts to behave in ways that make them more vulnerable to their predators; when the host is ingested, the parasite is able to infect the predator.

A parasite feeds on the host, but they generally do not destroy it. Parasites are usually smaller then the host. Parasites may have more than one host during its life cycle. The host evolved some defense mechanisms against the parasites; the most important is the immune responses such as cellular defenses. Also parasites can substantially decrease the host population sizes. The relationship between the parasites and the hosts is known as Parasitism. Tapeworms, blood sucking leeches and tape worms are typical examples of parasites. *Schistosoma mansoni*, endoparasite living in blood vessels of human

Parasites and their hosts have a close symbiotic relationship, so their populations also oscillate. This is demonstrated by winter moth caterpillars (the host species) and wasp larvae (parasites on the caterpillars). If the population of parasite increases, they kill their hosts, so their population decreases. This means there are fewer hosts for the parasite, so their population decreases. This allows the host population to recover, so the parasite population also recovers:



similar pattern is seen for pathogens and their hosts.

Some parasites change the behavior of their hosts in ways that increase the probability of the parasite being transferred from one host to another. Parasites can have significant direct and indirect effects on the survival, reproduction, and density of their host populations.Pathogens are disease-causing agents that have deleterious effects on their hosts (+/?) Pathogens are typically bacteria, viruses, or protists.Fungi and prions can also be pathogenic. Parasites are generally large, multicellular organisms, while most pathogens are microscopic. Many pathogens are lethal.

3.3 Symbiosis

The term symbiosis (living together) can be used to describe various degrees of close relationship between organisms of different species. Sometimes it is used only for cases where both organisms benefit; sometimes it is used more generally to describe all varieties of relatively tight relationships, i.e. even parasitism, but not predation. Some even go so far as to use it to describe predation. It can be used to describe relationships where one organism lives on or in another, or it can be used to describe cases where organisms are related by mutual stereotypic behaviors.

In either case, symbiosis is much more common in the living world and much more important than is generally assumed. Almost every organism has many internal parasites. A large percentage of herbivores have mutualistic gut fauna that help them digest plant matter, which is more difficult to digest than animal prey. Coral reefs are the result of mutalisms between coral organisms and various types of algae that live inside them. Most land plants and thus, one might say, the very existence of land ecosystems rely on mutualisms between the plants, which fix carbon from the air, and Mycorrhyzal fungi that help in extracting minerals from the ground. The evolution of all eukaryotes (plants, animals, fungi, protists) is believed to have resulted from a symbiosis between various sorts of bacteria: endosymbiotic theory.

In symbiosis, two or more kinds of organisms interact in often elaborate and more-or-less permanent relationships. All symbiotic relationships carry the potential for coevolution between the organisms involved, and in many instances the results of this co-evolution are fascinatingly complex.

Examples of symbiosis include **lichens**, which are associations of certain fungi with green algae or **cyanobacteria**. Another important example are **mycorrhizae**, associations between fungi and the roots of most kinds of plants. The fungi expedite the plant's absorption of certain nutrients, and the plants in turn provide the fungi with carbohydrates . Similarly, root nodules that occur in legumes and certain other kinds of plants contain bacteria that fix atmospheric nitrogen and make it available to their host plants. The major kinds of symbiotic relationships include

(1) **Commensalism**, in which one species benefits while the other neither benefits nor is harmed;

(2) **Mutualism**, in which both participating species benefit; and

(3) **Parasitism**, in which one species benefits but the other is harmed. Parasitism can also be viewed as a form of predation, although the organism that is preyed on does not necessarily die.

3.4 Herbivory

The term has been derived from the Latin words herba (herb) and vorare (to eat). The animals, which feed on plant only, are known as herbivores. Examples are goat, crow, buffalo,elephant, sheep, etc. Most herbivores feed on only one or a few plant species. Their diet may be some parts of the plant such as roots, leaves, seeds, sap and nectar. Some animals feed on algae or fungi. Many fishes eat diatoms (a group of algae).

Herbivory is the process whereby an animal eats a plant or a plant- like organism such as a seaweed or phytoplankton. These plants and plant-like organisms such as seaweeds and phytoplankton are called primary producers, as they use the sun's energy to make organic material. The animals in which such act of eating plants or plant-like organisms behavior is found determines the population abundance and dynamics of individual plant species. Herbivores regulate the species, composition of plant communities, the total amount of plant biomass in the ecosystems, and the magnitude of ecosystem functional processes such as primary production, decomposition and transfer of energy material up the food chain.

Herbivores require special adaptation for eating plants. Herbivores have flat molars and premolars to grind up plants. Some herbivores have a diastema (a space between the back molars and front teeth)which is used to carry plant materials . They lack canine teeth and incisors. Herbivores have eyes on the sides of their head allowing them to have a better view and avoid being prey to carnivores.

Herbivores often have physical features that help them eat tough, fiberous plant matter. Unlike herbivores and other consumers, autotrophs have tough cell walls throughout their physical structure. Cell walls can make plant material difficult. Herbivores have teeth that are highly specialized for eating plants. Because plant matter is often difficult to break down, the molars of herbivores are wider and flatter, designed to grind food, and aid in digestion. Herbivore incisors are sharp for tearing plants, but they may not be present on both the upper and lower jaw. White tail deer are a perfect example of an herbivore that has only lower incisors and a rigid upper jaw that assists in the tearing of plants. Many animals, such as horses and cows, have jaws that are capable of moving sideways. Elephants are herbivores, and their incisors are unlike those found in other animals. Odd as it may sound, a tusk is actually a tooth, an incisor, that has evolved into a different type of tool, often used for defense.

Many herbivorous mammals have wide molars. These big teeth help them grind up leaves and grasses. Carnivorous mammals, on the other hand, usually have long, sharp teeth that help them grab prey and rip it apart.

A group of herbivores called ruminants have specialized stomachs. For the digestion of plant matter, ruminant stomachs have more than one chamber. When a ruminant chews up and swallows grass, leaves, and other material, it goes into the first chamber of its stomach, where it sits and softens. There, specialized bacteria break down the food. When the material is soft enough, the animal regurgitates the food and chews it again. This helps break down the plant matter. This partially digested food is called cud. The animal then swallows the cud, and it goes into a second chamber of the stomach. Chemicals in the second chamber digest the plant material further, and it goes into the third chamber. Finally, the digested food goes to the fourth chamber, which is similar to a human stomach. Sheep, deer, giraffes, camels, and cattle are all ruminants.

Other herbivores eat only one part of a plant. An animal that specializes in eating fruit is called a **frugivore**. Oil birds, which live in northern South America, are **frugivores**. They eat nothing but the fruit of palms and laurels. The koala, which is native to Australia, eats little besides the leaves of eucalyptus trees. An animal that eats the leaves and shoots of trees is called a **folivore**. Pandas, which feed almost exclusively on bamboo, are folivores. Termites are insects that feed mostly on wood. Wood-eaters are called **xylophages**.

Many insects are herbivores. Some, such as grasshoppers, will eat every part of a plant. Others specialize in certain parts of the plant. Aphids drink sap, a sticky fluid that carries nutrients through the plant. Caterpillars eat leaves. The larvae, or young wormlike forms, of root weevils feed on roots. Asian long-horned beetles tunnel deep into the heart of a tree and eat the wood there.Honeybees feed on nectar and pollen from flowers.

Some herbivores consume only dead plant material. These organisms are called **detritivores**. Detritivores also consume other dead organic material, such as decaying animals, fungi, and algae. Detritivores such as earthworms, bacteria, and fungi are an important part of the food chain. They break down the dead organic material and recycle nutrients back into the ecosystem. Detritivores can survive in many places. Earthworms and mushrooms live in the soil. There are also detritivore bacteria at the bottom of the ocean.

3.5 Carnivory

This word has been derived from the Latin word **carnis** (flesh). The animals, which eat the flesh of other animals, are known as **carnivores**. They hunt and kill their prey and than feed on them; foe example, lion, tiger, leopard, etc. Although most of the carnivorous animals usually consume all parts of the bodies of their prey, some eat only certain parts such as skin, blood, flesh, etc.

A carnivore is an organism that mostly eats meat, or the flesh of animals. Sometimes carnivores are called **predators**. Organisms that carnivores hunt are called **prey**.

Carnivores are a major part of the food web, a description of which organisms eat which other organisms in the wild. Organisms in the food web are grouped into trophic, or nutritional, levels. There are three trophic levels. Autotrophs, organisms that produce their own food, are the first trophic level. These include plants and algae. Herbivores, organisms that eat plants and other autotrophs, are the second trophic level. Carnivores are the third trophic level. Omnivores, creatures that consume a wide variety of organisms from plants to animals to fungi, are also the third trophic level.

Autotrophs are called **producers**, because they produce their own food. Herbivores, carnivores, and omnivores are **consumers**. Herbivores are primary consumers. Carnivores and omnivores are secondary consumers.

Many carnivores eat herbivores. Some eat omnivores, and some eat other carnivores. Carnivores that consume other carnivores are called **tertiary consumers**. Killer whales, or orcas, are a classic example of tertiary consumers. Killer whales hunt seals and sea lions. Seals and sea lions are carnivores that consume fish, squid, and octopuses.

Some carnivores, called **obligate carnivores**, depend only on meat for survival. Their bodies cannot digest plants properly. Plants do not provide enough nutrients for obligate carnivores. All cats, from small house cats to huge tigers, are obligate carnivores.

Most carnivores are not obligate carnivores. A hypercarnivore is an organism that depends on animals for at least 70 percent of its diet. Plants, fungi, and other nutrients make up the rest of their food. All obligate carnivores, including cats, are hypercarnivores. Sea stars, which prey mostly on clams and oysters, are also hypercarnivores.

Mesocarnivores depend on animal meat for at least 50 percent of their diet. Foxes are mesocarnivores. They also eat fruits, vegetables, and fungi.

Hypocarnivores depend on animal meat for less than 30 percent of their diet. Most species of bears are hypocarnivores. They eat meat, fish, berries, nuts, and even the roots and bulbs of plants. Hypocarnivores such as bears are also considered omnivores.

The planet’s largest animal is a carnivore. The blue whale can reach 30 meters (100 feet) long and weigh as much as 180 metric tons (200 tons). It feeds by taking huge gulps of water and then filtering out tiny shrimp-like creatures called krill. The blue whale can eat about 3.6 metric tons (4 tons) of krill every day that’s about 40 million of the little creatures. The largest land carnivore is the polar bear, which feeds mainly on seals.

Carnivores have biological adaptations that help them hunt. Carnivorous mammals such as wolves have strong jaws and long, sharp teeth that help them grab and rip apart their prey. Plant-eaters, on the other hand, usually have big molars that help them grind up leaves and grasses.

Lions, cougars, and other cats have sharp claws that they use to hunt. Birds such as hawks and owls also hunt with their claws, called **talons**. Many carnivorous birds, called raptors, have curved beaks that they use to tear apart their prey.

Many carnivores grab their prey in their mouths. Great blue herons wade slowly through shallow water and then suddenly snatch a fish, crab, or other creature from the water. Toads grab mice in their mouths. Sperm whales dive deep into the ocean where they bite hold of squid.

Spiders capture their prey—usually insects—by trapping them in a sticky web. Other carnivores attack their prey with a bite or a sting that injects toxic venom into the victim. The venom either paralyzes or kills the prey.

Snakes such as king cobras have hollow fangs that act like needles to inject venom. **Cobras** mostly prey on other snakes. Jellyfish have stingers on their tentacles, which paralyze fish swimming nearby.

Most carnivores are animals, but plants and fungi can be carnivores also. The Venus flytrap is a plant that catches insects in its leaves. When an insect brushes against the sensitive hairs on the leaf, the leaf folds in two and snaps shut. The insect is trapped inside. Other carnivorous plants, such as the sundew, produce a sticky material that catches insects.

Fungi are a group of organisms that include mushrooms, molds, and mildew. Some fungi trap and consume tiny organisms. Most carnivorous fungi prey on microscopic worms called nematodes, which they trap with suffocating rings.

Certain types of carnivores have specific diets. Some, such as sea lions, eat mainly fish. They are called **piscivores**. Others, such as lizards, eat mainly insects. They are called **insectivores**. Many bats are also insectivores. One little brown bat can eat a thousand mosquitoes in an hour. Some insects are themselves insectivores. These include ladybugs, dragonflies, and praying mantises.

Carnivores that have been known to attack and eat human beings are known as **man-eaters**. Some species of sharks, alligators, and bears are called man-eaters. However, no carnivore specifically hunts human beings or relies on them as a regular food source.

Cannibals are carnivores that eat the meat of members of their own species. Many animals practice cannibalism. For some species, cannibalism is a way of eliminating competitors for food, mates, or other resources. Chimpanzees and bears, for example, will hunt and consume the young of family members, sometimes their own offspring. Praying mantis females will kill and eat the bodies of their mates.

Many carnivores are scavengers, creatures that eat the meat of dead animals, or **carrion**. Unlike other types of carnivores, scavengers usually do not hunt the animals they eat. Some, such as vultures, consume animals that have died from natural causes. Others, such as hyenas, will snatch meat hunted by other carnivores. Many insects, such as flies and beetles, are scavengers.

Some carnivores, including sea lions, feed often. Others, such as king cobras, can go months between meals.

Carnivores have a set of teeth that are very different from herbivores'. This makes sense, because they also have a different diet. A carnivore will use its teeth to kill a prey item before eating it. The sharp incisors and pointed canine teeth are perfectly designed for both incapacitating and eating a meal. A canine tooth can be easily identified, as it is the longer, pointed tooth located on either side of the incisors. The molars are fewer in number than other animals may have, mainly because so much of the work is done by the teeth in the front of the mouth. While the presence of canine teeth does not guarantee that an animal is a carnivore, it is an indicator that meat is some part of the diet.

Carnivores in the Food Chain

For a healthy ecosystem, it is important that the populations of autotrophs, herbivores, and carnivores be in balance. Energy from nutrients is lost at each trophic level. It takes many autotrophs to support a fewer number of herbivores. In turn, a single carnivore may have a home range of dozens or even hundreds of miles. A Siberian tiger, for instance, may patrol a range of 1,000 square kilometers (386 square miles).

In some places, the disappearance of large carnivores has led to an overpopulation of herbivores, disrupting the ecosystem. Wolves and cougars are traditional predators of white-tailed deer, for instance. But hunting and development have eliminated these predators from the northeastern United States. Without natural predators, the population of white-tailed deer has skyrocketed. In some areas, there are so many deer that they cannot find enough food. They frequently stray into towns and suburbs in search of food.

Carnivores depend on herbivores and other animals to survive. Zebras and gazelles once traveled in great herds over the plains of Africa. But these herds have shrunk and are now mostly confined to parks and wildlife reserves. As the numbers of these herbivores decline, carnivores such as African wild dogs, which prey on them, also decline. Scientists estimate that only 3,000 to 5,500 African wild dogs remain in the wild.

3.6 Species Richness

Species richness is the number of different species represented in an ecological community, landscape or region. Species richness is simply a count of species, and it does not take into account of the abundances of the species of their relative abundance distributions. It gives as much weight to those species which leave very few individuals as to those which leave many individuals .Thus , one daisy flower has as much influence on the richness of as area as 1000 buttercups flowers.

Species richness is often used as a criterion when assessing the relative conservation values of habitats or landscapes. However species richness is blind to the identity of the species. An area with many endemic or rare species is generally considered to leave higher conservation value than another area where species richness to similar but all the species are common and widespread .

Species richness is related to a community's geographic size.

The species-area curve quantifies what may seem obvious: the larger the geographic area of a community, the greater the number of species.Larger areas offer a greater diversity of habitats and microhabitats than smaller areas.

In conservation biology, developing species-area curves for the key taxa in a community allows ecologists to predict how loss of habitat is likely to affect biodiversity.

Species richness on islands depends on island size and distance from the mainland.

Because of their size and isolation, islands provide excellent opportunities for studying some of the biogeographic factors that affect the species diversity of communities. "Islands" include oceanic islands as well as habitat islands on land, such as lakes, mountain peaks, or natural woodland fragments. An island is thus any patch surrounded by an environment unsuitable for the "island" species. Robert MacArthur and E. O. Wilson developed a general hypothesis of island biogeography to identify the key determinants of species diversity on an island with a given set of physical characteristics. Imagine a newly formed oceanic island that receives colonizing species from a distant mainland.

3.7 Species Evenness

Evenness to a measure of the relative abundance of the different species making up the richness of an area. In refers to how close in number each species in an environment is. Mathematically, it is a measure of biodiversity which quantifies how equal the community is numerically. So if there are 40 foxes, and 1000 dogs, the community is not very even. But if there are 40 foxes and 42 dogs; the community is quite even.

To give an example , we might have sampled two different forest area for animals .sample from the forest field consists of 300 jackals, 360 foxes and 340 wild dogs. The sample from the second field comprises 225 jackals , 620 foxes and 155 wild dogs. (see the table below).both sample have the same richness(3 species) and the same total number of individuals (1000) . however, the first sample ha s more evenness than the second. This is because the total number of individuals in the sample is quite evenly distributed between the three species. In the second sample, most of the individuals are foxes, with lesser number of jackals and wild dogs , sample second is there for considered to be less diverse then sample one.

NUMBER OF INDIVIDUALS

ANIMAL	SAMPLE 1	SAMPLE 2
JACKALS	300	225
FOX	360	620
WILD DOG	340	155
	-------	--------
TOTAL	1000	1000

A community dominated by one or two species is considered to be less diverse than one in which several different species have a similar abundance . As species richness and evenness increases , so diversity increases .

Species Diversity

A diversity index is a mathematical measure of species diversity in a given community. It is based on the species richness (the number of species present) and species abundance (the number of individuals per species) .The more species you have, the more diverse is the area It provides the important information about rarity and commonness of species in a community The ability to quantify diversity in this way is an important tool for biologists trying to understand community structure.

3.8 Simpsons's Diversity Index

In 1949, **Edward H. Simpson** measured the degree of concentration when individuals were classified two types.The same index was rediscovered by **Orris. .C. Herfindahl** in 1950 while economist **Albert O. Hirschman** , introduced the square root of the index in 1945. As a result, the same measure is known as **Simpson index** in ecology, and as the **Herfindahl index** or the Herfindahl –Hirschman index (HHI) in economics.

Simpson's index (d) measures the probability that two individuals randomly selected from a sample will belong to the same species.

$$D = 1-\left(\frac{\sum n(n-1)}{N(N-1)}\right)$$

Where, n = The total number of organisms of particular species.

N = The total number of organisms of all species.

The value of D ranges between 0 and 1.With this index , 0 represents infinite diversity and 1, no diversity .i.e.the bigger the value of D, the lower the diversity.

3.9 Shannon's Diversity Index

The structure of biotic community can be summarized in diversity index derived from information theory. Since some species may be superabundant a large probability exists that individual observed during sampling belongs to a species previously recognized. Thus considerable repetition of information exists and redundancy is high. Information per individual is low and is reflected in low index of diversity. The more species present in a community and more equal their abundance, the greater the uncertainty and hence greater the diversity. We many assume that in a very diverse community we approach every individual carries a higher amount of information; it can be said that more diverse community carries more information. Diversity index based on information theory was first used by **Margalef** (1958) to analyse natural communities. The technique equates diversity with information. Maximum diversity and thus maximum information exists in a community of organism when each individual belongs to a different species. Minimum diversity or high redundancy exists when all individuals belong to the same species.

A detailed description of the theory behind these techniques is given by **Wilhm** and **Dorris** (1968) and **Brilloun** (1960). The formula used in calculations of these indices are as follows

The diversity per individual is

D = - □ p/log 2 p/

Where p/ = probability that any individual selected at random belongs to / th species.

The size of the unit depends on the value assigned to the logarithms. Commonly chosen logarithmic bases are the number 2, e and 10. Information theorists generally use logarithms to base 2 and the information units then call "binary digits" or "bits". When natural logarithms are used the unit is called a "natural bel" or a "nat" (Maclntosh, 1967) and with logarithms to base 10 the units becomes a "bel" or a "decit" (Pielou, 1966). In ecology the units to be used and the name to be given it have not yet become standardized.

Reason for more popularity of Shannon's Diversity Index

The index is very useful and most popular because (1) it is relatively insentitive to the size of the sample embodying the usual pattern of distribution of individual in species; (2) it is also insensitive to any random selection with in the sample and if possible to operations that are not strictly random; (3) it needs least taxonomic expertise just to recognize species not to identify them by name. Error resulting from failure to distinguish between closely similar species or counting life history stages as separate species are not critical because (a) closely related species are not apt to be found in the same sample (competitive exclusion principle) and (b) different life history stages are in themselves part of diversity (Odum, 1971) Another advantage of using d is that it permits us to take into account the hierarchical nature of biological classification. Suppose we were comparing two populations and that both had the same number of species in the same relative proportions, whatever function of these proportions we use as a measure of diversity, the diversity of the two populations must be equal; but, if in one population all the species blonged to a single genus and in the other every species belonged to different genus, it would be reasonable to regard the latter community as the more diverse of the two. This suggests that it would be desirable to be able to split the diversity measure into a generic, a specific, or even at family order, or higher level of taxonomic hierarchy (Pielou, 1967 & 1969).

Example Diversity Index

The diversity indices, unlike biotic indices, are values, derived mathematically from quantitative data. They make no use, however, of the autecological information regarding the response of individual species (Hawkes, 1977).

Diversity indices derived from information theory were first used by Margalef (1958) to analyse natural community of organisms. The theory underlying these techniques is discussed in detail by Wilhm and Dorris (1968). The species diversity index for community as adopted by Trivedi (1979) from Shannon and Weaver (1963) as follows :

$$D = -\Sigma\ (N_1/N) \times \log 2\ (N_1/N) \text{ or } -\Sigma P_1 \log P_1$$

Where

d = Diversity index

N_1 = Importance value for each species (- no. of individuals in each species)

N = Total of importance values (= Total number of individuals)

P_1 = Importance probability for each species = N_1/N

The diversity index and the corresponding water quality is given in table (Trivedi 1979).

Table : Diversity Index and the Quality of Water

S.No.	Diversity index based on Information theory	Water Condition
1.	> 4	Clean no pollution
2.	3 - 4	Light pollution
3.	2 - 1	Modeatre pollution
4.	< 2	High pollution

One theoretical consideration that is not taken into account in biological indices on diversity indices is the interference due to determinants such as water currents, erosion, Nature of substratum, tiffles, ridges etc. (Hawkes, 1977)

Work Done in India

In India little work has been done on the biological indicators of water quality (Krishnamoorthy et al., 1978 ; Krishnamoorthy and Sarkar 1979 ; Trivedi, 1979)

The Indicator species may vary in time and space. Sphaeiotilus natans is found only in winter season and just after the discharge of rayon effluents. Similarly, Oscillatoria spirulina complex is found in the summer season just 5 km down stream of the discharge point of rayon effluents (Trivedi 1979).

Desulphovibrio desulphuricans and Beggiatoa alba are considered to be the best indicators of river water polluted with effluents of rayon industries (Trivedi, 1979).

The Spirulina Oscillatoria complex among algae and Tobrillus-Chironomous among animals are also considered to be tolerant of acidic effluents and the species diversity was found to be reduced by such effluents (Trivedi 1979).

3.10 Community Structure & Attributes

Community is a huge or large unit, it is formed by different populations. A community is composed of animals and plants with environment. The concept of community is studied from past time, **Theophrastus** (372- 250 B.C.) first defined plant communities. Forbes was first scientist who reported different collection of species. **Carl Mobius** (1880 – 1887) recognized natural community and according to him "Collection of species of any living being is community". A community may be made basically of animals or plants but most communities include both. These population or species group are mutually interdependent and thus form a soil sustaining community. **Mobius** proposed a new name '**biocenose**' for community. **Charles Elton** (1920) stated that ecological niches are related to community. **Hein** (1927) pointed out four basic factors which are responsible for forming and maintaining communities as food chain, size of food, niches, and pyramid of numbers. **Clements** (1936), **Tansley** (1939) described different aspect of communities.

The concept of community is important principles in ecological thought and practice. It shows the fact that various organisms usually live together in an orderly manner. When the several species overlap the population of different species coexists in limited area forms community.

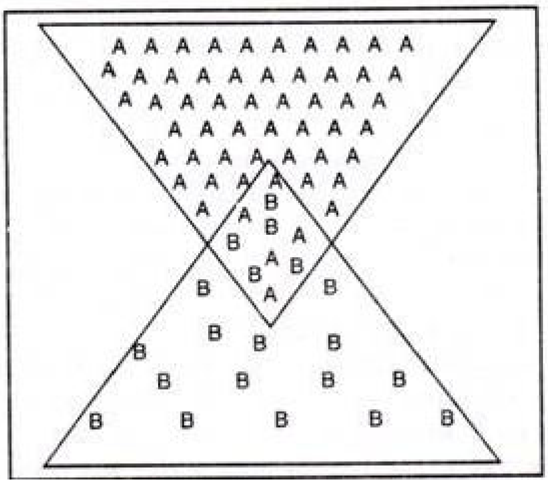


Fig : Showing the population of species A and B

As in figure 1 shows that community is characterized by having definite species composition. Mostly the population of one species and another population species overlaps and forms one community. One community is separated from another community by a line of demarcation.

Community is recognized on the basis of habitat, species of organisms. As the community goes, so goes the individuals. There are many ways by which the individual growth can be controlled in any community. If it is encouraged they increase and if discouraged they reduces. For example by bringing fluctuation in water level mosquitoes can often be controlled more efficiently by modifying the aquatic community entirely.

The community concept is one of the most important principles in ecological thought and ecological practice of ecology because as the community goes, so goes the individuals .Thus often the best way to control a particular individual modify community rather than to make a direct attack on the individual.

The community is defined in various ways as-

According to **Clarke**, "A community is defined as a group of mutually adjusted plants and animals inhabiting a natural area".

Krebs (1972) referred "A community is an assemblage of population of plants and animals in a particular area or habitat".

Smith (1996) defines "Community as a naturally occurring, mutually sustaining and interacting assemblage of plants and animals living in the same environment and fixing, utilizing and transferring energy in same manner". In this definition, community encompasses all organisms of a given sight. They belong to at least more than one trophic level.

V.E.Shelford explained that “Community is a collective group of living organisms of same taxonomic composition and is relatively uniform”.

General Characteristics Of Natural Community

1. Community diversity

Community is a heterogeneous assemblage of plants and animals. The animals and plants are drawn from different taxonomic groups. They may be distinctly related or closely related. But they are interdependent and interacting in many ways. They are dependent on the abiotic factors of the habitat.

Community diversity is of two types-if the number of species present is maximum then it refers richness and if it is equitable then called **evenness**.

In any ecosystem level of diversity is recognized as follows-

a) **Alpha diversity** –the diversity within a particular habitat or one specific community.

b) **Beta diversity** - the diversity among several communities

c) **Gamma diversity** - the diversity present across geographic area

For example-diversity of invertebrate components of marine habitat are compared. The sequence of decreasing diversity from tropical shallow water (TSW) to boreal estuary (BE) is seen from (fig.2)

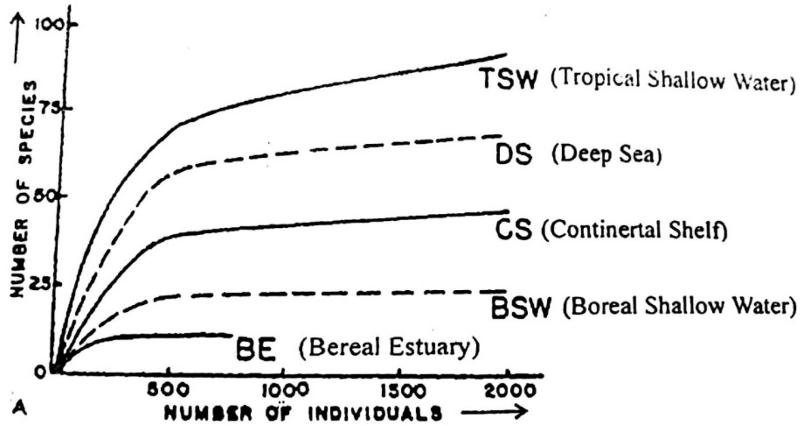


Fig : Showing diversity of composition of species in sample of marine sediment of polychaetes (of 5 habitats).

2. Structure

Each community has a definite structure. It is formed of three groups of organisms, namely producers, consumers and decomposers.

(a) Producers

The green plants constitute the producers. They are called the **autotrophs**. They can synthesize starch by photosynthesis utilizing chlorophyll, Co_2, water, mineral and solar energy. The producers form the main source of energy for the components of the community. **eg**.Plants, Phytoplanktons, etc

(b) Consumers

Consumers are the **heterotrophs**. They cannot produce food, utilizing abiotic factors. But they depend on the producers and other organisms of the Community for there food. Consumers are basically of two types, herbivore and carnivore.

i) Herbivores: Herbivore are the animals which eat the producers. They are also called **primary consumers** because they form the first order of consumers.**eg.** Deer, rabbits in forest Community: Zooplanktons and plant eating fishes of pond Community.

ii) Carnivores: Carnivores are animals which eat other animals for their food. These are also called **secondary consumers** because they form the second orders of consumers.**eg.** Fox, Lion and Tiger of forest community, Fishes, Frogs and Snakes of pond community.

Carnivores are further sub-divided into primary carnivores, secondary carnivores and tertiary carnivores.

The primary carnivores are dependent on herbivores for their food. The secondary carnivores depend on primary carnivores and tertiary carnivores depend on secondary carnivores.

3. Community Dominants

A community is formed of many species. Of these one or a few species play a dominant role in community by virtue of their number, size and activities. These species are called **community dominant**. The removal of community dominant from a community affects the community drastically. In a forest community the trees form the community dominants. In a grassland community, the grasses form the dominant groups

4. Stratification

It refers to the arrangement of the components (organisms) in different layers in a community. There are two types of stratifications, namely

(a) Vertical stratification

(b) Horizontal stratification

(a) Vertical stratification

It refers to the vertical distribution of organisms in a community. Vertical stratification is found in forest community, grassland community and aquatic communities.

Vertical stratification is clearly seen in a forest community. A forest is formed of five layers. They are 1.Trees (upper layer) 2. Shrubs 3. Herbs 4. Forest floor and 5. The subterranean (low layer)

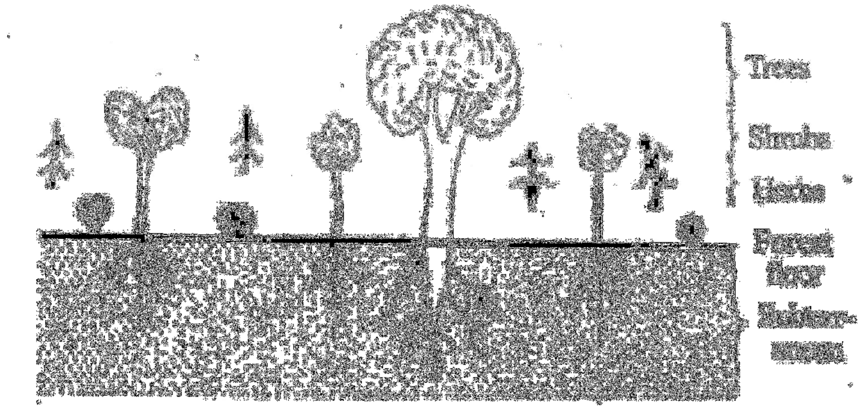


Fig : Vertical stratification in a forest community

Each layer has its own fauna. The upper layer of trees is formed of branches and leaves. It is occupied by animals like lizards, tree-frogs, squirrels, monkeys, loris, etc.

Shrubs and herbs are occupied by plant eating insects and spiders.

The forest floor is occupied by dead organic matter, litter, fungi, bacteria, snails, etc.

The subterranean layer is formed of roots, tubers, earthworms, insects, protozoans, bacteria, etc.

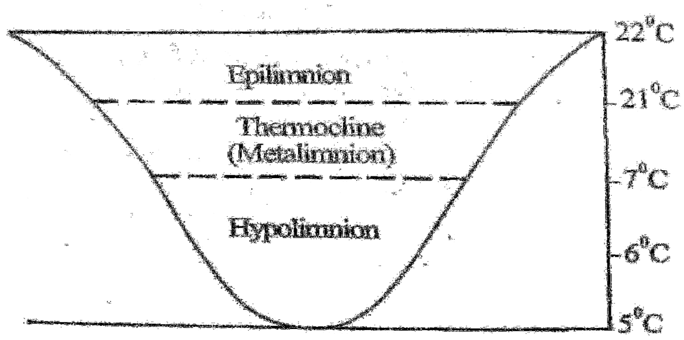


Fig : Summer stratification of lake

In aquatic communities, such as large lakes and oceans, temperature causes, thermal stratification. It is formed of three layers, namely an upper **epilimnion**, a middle **thermocline** (metalimnion) and a lower **hypolimnion**.

Similarly the penetration of light causes three layers, namely the euphotic zone, the disphotic zone, and the aphotic zone.

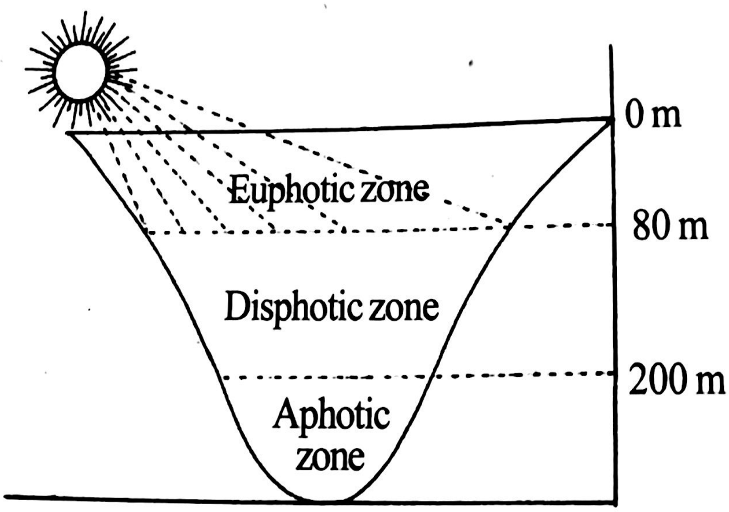


Fig : Light penetration in the sea

2. Horizontal stratification

It refers to the distribution of individuals on a horizontal plane in the community. In a terrestrial community, the individuals may be distributed on the floor in three ways namely uniform, clumped, and random. In uniform distribution, the species are distributed uniformly throughout the community. In clumped distribution, the individuals aggregated into groups. In random distribution, the individuals are irregularly placed. In a pond or lake three horizontal zones are seen. They are the littoral-zone, sub-littoral zone and the profundal zone. Similarly, in a marine habitat four horizontal zones are recognized. They are

1. The neretic zone,
2. The oceanic zone
3. The archibenthic zone and then
4. The abyssal benthic zone

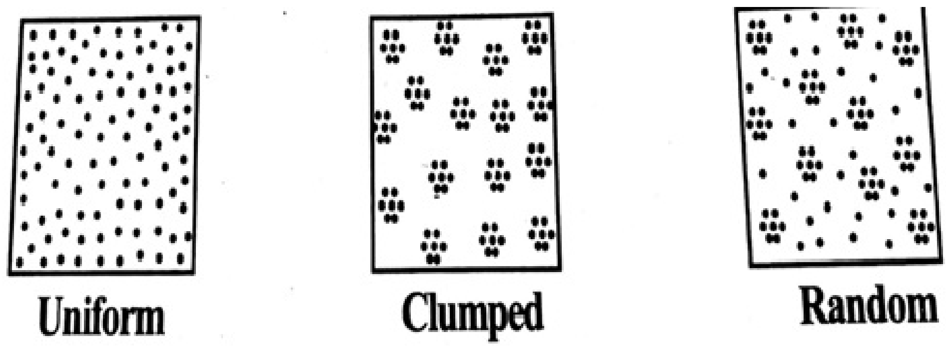


Fig : Distribution of individuals in plants

5. Community Periodicity

"Periodicity refers to the rhythmic activity of an organism for food, shelter and reproduction". The periodicity of a community is correlated to seasonal changes, day and night, lunar rhythms and the inherent property of the animals.

A community is formed of many species. The breeding seasons of different species vary with seasons. Variations in temperature and light causes migration, aestivation and hibernation.

The daily periodicity is due to day and night. Accordingly, some organisms in the community are active in the day (**diurnal**).The microorganisms like copepods exhibit vertical diurnal migration. They move towards the surface during the night and towards the bottom during the day. Photosynthesis and the opening of flowers are daily periodicities in plants.

Marine community exhibits **lunar** periodicity. For example, in polychaetes swarming and spawning occur on full moon day.

6. Community Interdependence

The various species in a community are interdependent. The interdependence may be for food, shelter and reproduction.

Interdependence for Food

In a community, the herbivores are dependent on plants for their food. The carnivores are dependent on herbivores for their food.

Interdependence for Shelter

Plants provide protection for animals from the sun and enemies.

Interdependence for Reproduction

Flowering plants depend on insects for pollination.

3.11 Ecotone and Edge Effect

Ecotone

A transitional area of vegetation between two different plant communities, such as forest and grassland. It has some of the characteristics of each bordering biological community and often contains species not found in the overlapping communities. An ecotone may exist along a broad belt or in a small pocket, such as aforest clearing, where two local communities blend together. The influence of the two bordering communities on each other is known as the edge effect. An ecotonal area often has a higher density of organisms of one species and a greater number of species than are found in either flanking community. Some organisms need a transitional area for activities such as courtship, nesting, or foraging for food.

Ecotones also appear where one body of water meets another (e.g., estuaries and lagoons) or at the boundary between the water and the land (e.g., marshes). Freshwater and marine ecotones are characterized by the presence of large plants that rise from roots attached to the submerged substrate, and thus they occur in areas where amplelight is available at the bottom of the basin to permit growth.

Edge Effect

The **edge effect** is an ecological concept that describes how there is a greater diversity of life in the region where the edges two adjacent ecosystems overlap, such as land/water, or forest/grassland. At the edge of two overlapping ecosystems, you can find species from both of these ecosystems, as well as unique species that aren't found in either ecosystem but are specially adapted to the conditions of the transition zone between the two edges.

For the sake of clarity, we must first define some key ecological terms.

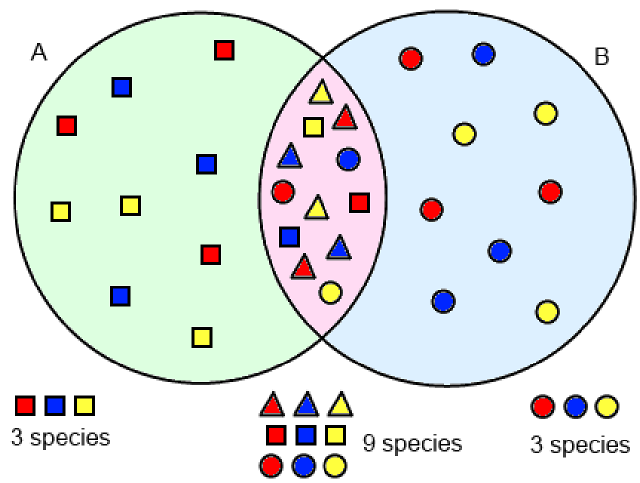
An ***edge*** is the boundary or interface between two biological communities (*e.g. forest and grassland*) or between different landscape elements (*e.g. land and water*). An ***ecotone*** is the transition zone along the edges of two adjacent ecological communities, where one ecological communities meets the other (*e.g. the area between forest and grassland*). The transition from one ecosystem to the other can be a very gradual or a very sharp one. Edge environments occur naturally at many ecosystem boundaries, some examples of these are:

(i) along the perimeter of bodies of water, such as river, lakes and streams

(ii) where forests verge on rock outcrops, riparian areas (i.e. river banks), grasslands
(iii) along outcrops of exposed rock and cliffs
(iv) where forested areas border clearings
(v) where sharp discontinuities in soil type or hydrology exist
(vi) where estuaries meet the ocean

The following diagram illustrates how the edge effect operates :

In this example, each ecosystem, labelled A and B, contain only three species, coloured red, blue and yellow. Ecosystem A contains 3 species represented by squares and ecosystem B has 3 represented by circles. In the region where they overlap, called the ***ecotone***, there are red, blue and yellow squares and circles. The combination of squares and circles (which represent six species) produce unique conditions which can now support three new species, represented as red, blue and yellow triangles. So, while ecosystems A and B each contains three species, the overlapping transition zone contains nine. This increase of diversity that results from ecosystems overlapping is known as the ***edge effect***.



(The 'edge effect' – Where two ecosystems overlap, the overlapping area supports species from both, plus another species that is only found in the overlapping area.)

These ecotones (the regions where the edges of two ecosystems overlap), contain a greater diversity of species than either of the two separate ecosystems, and have significantly greater productivity, for the following reasons:

(i) Resources from both ecosystems can be accessed in the one place.
(ii) Conditions such as air temperature, humidity, soil moisture and light intensity levels all change at edges.

(iii) Variations in the conditions at the edges can create favourable microclimates which can support unique species.

(iv) Increased availability of light to plants along the edges allows more plants to be supported (greater diversity) and increases productivity.

(v) Increased plant diversity increases herbivorous insects, which increases birds, and ultimately predators.

(vi) Ecosystem edges and borders act as 'energy nets' or sieve, capturing the massive movement of materials, nutrients and energy across their boundaries – leaves and soil are blown by the wind against barriers, shells wash up on the beach, etc.

(vii) Adjacent ecosystems are connected via flows of energy, material (nutrients) and organisms across their boundaries, and these flows can exert strong influences on the fertility and productivity of ecosystems.

It is important to note that the environmental conditions at the edges of ecosystems usually different from those deep within the ecosystems themselves.

The increased productivity and diversity resulting from the edge effect is clearly observable in Nature. Mangrove ecologies (land/sea interface) and reef ecologies (coral/ocean) interface and some the the most highly productive natural systems. Riparian areas (the banks of rivers and streams) are very rich in biodiversity. Traditional human settlements are usually located at the highly productive transition zones between ecosystems, such as alongside rivers, estuaries or ocean, between foothills and plains, the outskirts of forest, or any combinations of these.

Ecological niche

The functional unit of the community is niche or in other words the position or working status of any organism is niche in the community. Ecological niche is structural changes, physiological response and behavior of organisms. For example, lion is carnivore in forest community and deer is herbivore. Even sometime they are herbivore but still differ as elephant feed on leaves of big trees, deer on shrubs and grasshopper on grasses. According to Odum in different geographical areas the organisms occupy same ecological niche. As deer is found in different place but eat grass only. Ecological niche is divided in three parts-Habitat or **spatial niche**, **trophic niche** and **hypervolume** niche. Each organism in a community confronts the challenge of survival in a different way. The niche an organism occupies is the total of all the ways it uses the resources of its environment. A niche may be described in terms of space utilization, food consumption, temperature range, appropriate conditions for mating, requirements for moisture, and other factors.

Sometimes species are not able to occupy their entire niche because of the presence or absence of other species. Species can interact with one another in a number of ways, and these interactions can either have positive or negative effects. One type of interaction is interspecific competition, which occurs when two species attempt to use the same resource and there is not enough of the resource to satisfy both. Physical interactions over access to resources—such as fighting to defend a territory or displacing an individual from a particular location—are referred to as interference competition; consuming the same resources is called exploitativecompetition.

Fundamental niches are potential; realized niches are actual

The entire niche that a species is capable of using, based on its physiological tolerance limits and resource needs, is called the fundamental niche. The actual set of environmental conditions, including the presence or absence of other species, in which the species can establish a stable population is its realized niche. Because of interspecific interactions, the realized niche of a species may be considerably smaller than its fundamental niche.

Competition between species for niche occupancy

In a classic study, J. H. Connell of the University of California, Santa Barbara, investigated competitive interactions between two species of barnacles that grow together on rocks along the coast of Scotland. Of the two species Connell studied, *Chthamalus stellatus* lives in shallower water, where tidal action often exposes it to air, and *Semibalanus balanoides* (called *Balanus balanoides* prior to 1995) lives lower down, where it is rarely exposed to the atmosphere In these areas, space is at a premium. In the deeper zone, *S. balanoides* could always outcompete *C. stellatus* by crowding it off the rocks, undercutting it, and replacing it even where it had begun to grow, an example of interference competition.

When Connell removed *S. balanoides* from the area, however, *C. stellatus* was easily able to occupy the deeper zone, indicating that no physiological or other general obstacles prevented it from becoming established there. In contrast, *S. balanoides* could not survive in the shallow-water habitats where *C. stellatus* normally occurs; it does not have the physiological adaptations to warmer temperatures that allow *C. stellatus* to occupy this zone. Thus, the fundamental niche of *C. stellatus* includes both shallow and deeper zones, but its realized niche is much narrower because *C. stellatus* can be outcompeted by *S. balanoides* in parts of its fundamental niche. By contrast, the realized and fundamental niches of *S. balanoides* appear to be identical.

Concept of community

There are two views regarding the nature of community. They are

(a) Organismic concept and

(b) Indiviualistic concept

(a) Organismic Concept

This concept was proposed by **Clements** (1916) .This concept states that the community has all the characteristics of an organism such as development, dominance, and co-operation and so on. An organism is formed of cells and tissues. The tissues have certain characteristics and functions above those of the cells. Similarly, community is formed of many species or populations. All the species in a community are integrated together. The community has certain characteristics and functions more than those of the populations.

(b) Individualistic Concept

This concept was proposed by **Gleason** (1926). It considers the species as the essential units of the community. Each species behave independently and responds to the physiological and biotic environment according to their own genetic characteristics. They are not integrated together. The community is a collection of species requiring the same environmental conditions.

Ecological succession

The process of development of new communities in an area is called ecological succession. It can be defined as "An orderly and progressive replacement of one community by another till the development of a stable community in that area". (Smith, 1965). The communities in any area are not stable. They are changing into other forms of communities from time to time. Thus in a particular area one community may be replaced by other community or by series of communities.

For example, a pond community can be transformed into a marshland community, if the pond is gradually filled with sand and mud. The marshland in the course of time may give rise to a grassland community or a forest community according to the environment factors prevailing there.

Ecological succession is directional and predictable. The succession is caused due to the modification of the physical environment. There is an increase in structural complexity during succession. The kinds of animals and plants change continuously with succession. The diversity of species tends to increase with succession. The microorganisms and heterotrophic animals reach their maximum diversity in the later stages of succession. The microorganisms and heterotrophic animals reach their maximum diversity in the later stages of succession. Biomass increases. As biomass increases, many new habitat niches are created.

The succession of a community can be compared to the embryogenesis of an organism.

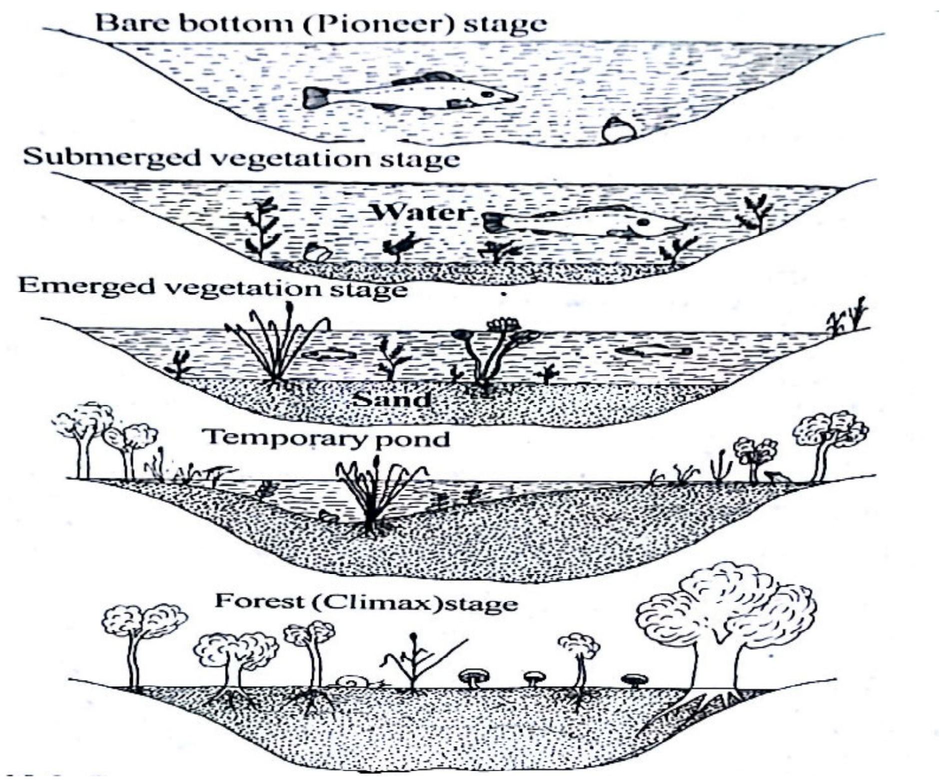


Fig : Ecological succession. A pond community is replaced by a forest community through ecological succession.

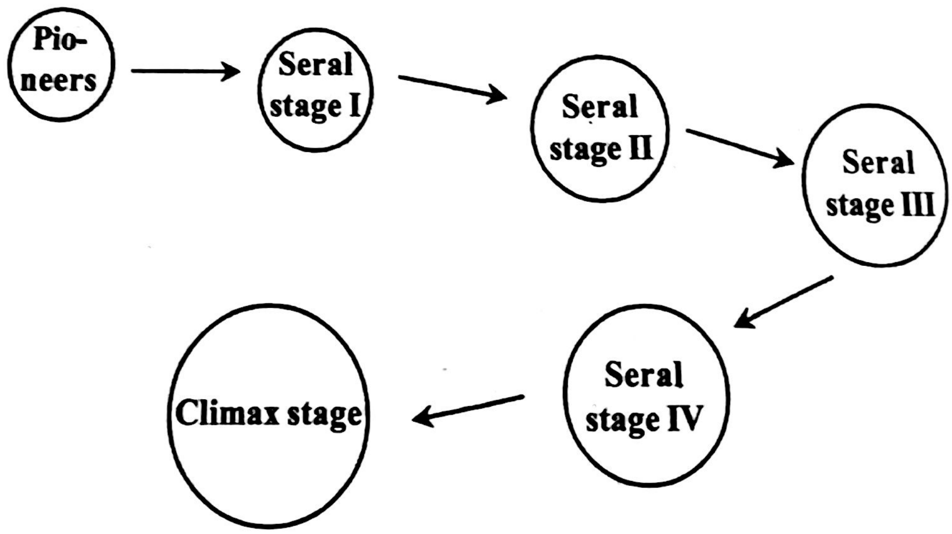


Fig : Diagrammatic representation of ecological succession

In the development of a community, a series of communities develop and they replace one another in an orderly sequence until the stable community is produced. The various developmental stages of a community are called sere and each stage is called a seral stage. The first seral stage is called the pioneer community. The first stable community is called climax community.

Community: Composition

Community may vary in their size. They may be large or small. Large community may extend over areas of several thousands of square kilometers, e.g., forests. The desert communities are comparatively smaller with dimensions in hundreds of kilometers. The meadows, rivers, ponds, rocky plateaus communities may occupy a more restricted area. The communities of microorganisms are very small in their size because they are found in microhabitats, e.g., on leaf surface, fallen log, litter, soil etc.

The number of species and population abundance in community vary greatly. Each community is characterized with a group of diverse species, and all these species are not equally important but these are only a few overlapping species which by their bulk and growth modify the habitat and control the growth of other species of the community, thus forming a sort of characteristic nucleus in the community. These species are called dominants.

In most of the communities, only a single species, due to being particularly conspicuous, is dominant, and in such single species, due to being particularly conspicuous, is dominant species as for example, spruce forest community. In other communities, there may be more than one dominants as in oak –hickory forest community.

The composition of a plants and animals in any habitat or ecosystem is dependent upon the frequency of the physical environmental conditions. The ecological amplitude of species population is directly related to abiotic conditions of the community. Thus the physical conditions and biotic component determine the type of community. If both factors (abiotic and biotic) have good interaction then that community survives and develops more.

Community: Structure

Communities have their structure which is recognizable in a pstial arrangement of their members. Structurally, a community may be classified as

Horizontal community: This kind of community is divided into subcommunities. These are the units of homogenous life–form and ecological relation. Such community constitutes the **zonation**, for example the zonation of **forest community.** It has different distinct vegetational types on a mountain which may be latitudinal as well altitudinal zonations of vegetation. These zonation have relation with climatic factors.

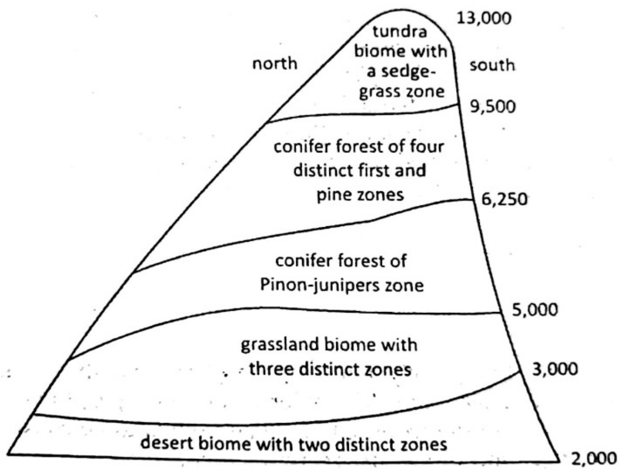


Fig : Showing zonation (horizontal vegetation zones) on one of the mountains of Western North America

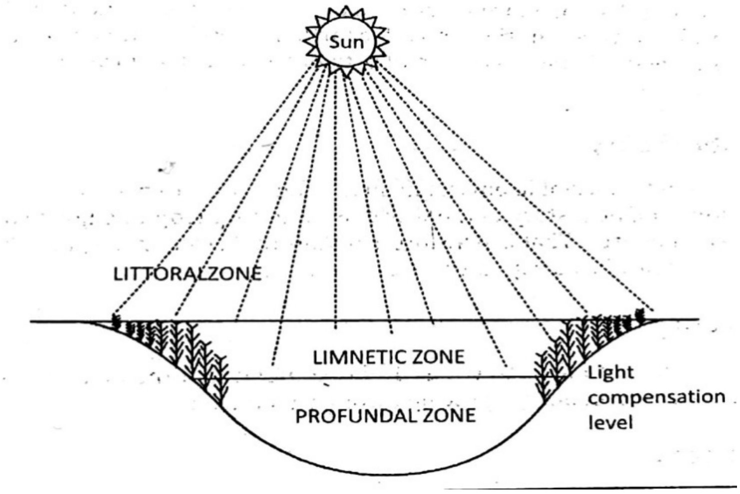


Fig : Diagrammatic sketch showing three major zones of a freshwater body as, lake

Shallow ponds have zonation. The deep ponds and lakes may have three zones like littoral zone, limentic zone and profundal zone. In each zone, organisms differ from each other. Another aspect of structure that is more common is stratification. It is very complex process and is characterized by a number of vertical layers of the species and each is made up of a characteristic growth form. It involves vertical rather than horizontal change s within the community. The horizontal zone may be recognized in distinct vertical storeys.

The grassland communities have subterranean floor and contain basal portions of the vegeatations, e.g. rhizomes of grass covered by litter and debris of plants as well as animals, and herbaceous substratum consisting of upper parts of the grasses and herbs with a characteristic fauna .The stratification in a forest community is most complicated and have as many as five following vertical subdivisions: (1) Subterranean subdivision (2) Forest floor, (3) Herbaceous vegetation, (4) Shrubs and (5) Trees.

The tropical rain forests may be divided into eight vertical strata on the basis of light and relative humidity requirements. The stratification can be observed in the above ground parts. The stratification may also be observed in the underground parts like roots, rhizome or other structure below the soil.

3.12 Self-Learning Exercise

Section -A (Very Short Answer Type):

1. Biotic community is defined as a group of________populations living at one place and________with one another in several ways.

2. Symbiosis or Mutualism is an interaction between two organisms of different species where both the partners are________but, can not live________
3. Competition is a ___________between two or more organisms for obtaining the same___________
4. Stability of a biotic community is mainly governed by its_________ or number of _________ and their interactions.
5. Lichen is a composite entity which is formed jointly by an alga and a fungus. (True / False)
6. The first biotic community which develops in a bare area is called pioneer community. (True / False)
7. Primary succession is a biotic succession that occurs on a previously sterile or primarily bare area. (True / False)

Section -B (Short Answer Type) :

1. Define commensalism with suitable example ?
2. What is different between Mutalism and Commensalism ?
3. Write adaptation of Carnivorus animals ?
4. Define species Richness and Evenness ?
5. Explain Ecological Niche.
6. Role of Mutalism in Evolution ?
7. Difference between external and internal parasites ?

Section -C (Long Answer Type)

1. What is Diversity Index ? Discuss and write its important.
2. Write an essay on Nature of community and attributes.
3. Discuss role of interspecific competition in evolution.
4. Write short notes on Herbivorae and Carnivore.
5. Explain Edge effect ? Discuss Ecotone.

Answer Key of Section-A

1. Different, Interacting
2. Benifited, Separetely
3. Rivalry, Resource

4. Diversity
5. True
6. True
7. True

3.13 References

- Ecology, Environment and Resource Conservation – Singh, Singh and Gupta
- Ecology - Odum

Unit - 4

Ecological Succession and Ecosystem

Structure of the Unit

4.0 Objectives

After going through this unit you will come to know about the trend of formation of ecosystem communities, how succession begin in any barren area and changes involve in climatic factors. You will learn the composition of ecosystem i.e. structure of ecosystem and the function of ecosystem, their interaction with other component of ecosystem, flow of energy in ecosystem from ultimate source of energy, Sun to all the component of ecosystem and the cycling of minerals among the ecosystem. Further in this unit you will understand the major types of ecosystem like Terrestrial ecosystem, Aquatic ecosystem, grassland ecosystem etc.

4.1 Introduction

Environment is always kept on changing over a period of time due to variations in climatic, physiographic factors and the Activities of the species of the community themselves. These influences bring about marked changes in the dominants of the existing community.

Any ecological unit that includes all the organisms (i.e., the communities in a given area) which inter act among themselves and with the physical environment, so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycle (i.e. Exchange of materials) within the system, is known as ecological system or ecosystem. There exist nutritional relationships (or food links) amongst the living organisms of such a system. Keeping this in view, the earth can be considered as a giant ecosystem where abiotic and biotic components are constantly ting and reacting upon each other bringing forth structural and functional changes in it. We generally study nature by making its artificial subdivisions into units of smaller ecosystems (such as terrestrial forest, desert, grassland aquatic fresh water marine; and man-made cropland, etc.).

4.2 Ecological succession

Communities are never stable, but dynamic, changing more or less regularly over time and space. They are never found permanently in complete balance with their biotic component or with the physical environment, hence replaced by another community at the same place. This process continues and successive communities develop one after another over the same area, until the terminal final community again becomes more or less stable for a period of time. This occurrence of relatively define sequence communities over a period of time in the same area is known as ecological succession.

Odum(1971) preferred to call this orderly process as ecosystem development rather than the more often known often ecological succession. He made an elaborate statement to define this process, and in his own words ‘ecosystem development’ or what is more often known as ecological succession, may be defined in terms of the following parameters:

(1) It is orderly process of community development that involves changes in species structure and community processes with time, it is reasonable directional and therefore, predictable.
(2) It results from modification of physical environment by the community that is,succession is community controlled even though the physical environment determines the pattern,the rate of change,and often sets limits as to how far development can go.
(3) It culminates in a established ecosystemin which maximum biomass(or high information content)and symbiotic function between organisms are maintained per unit of available energy flow.

Causes of succession

It is a process more properly a series of complex processes it is natural that there may not be single cause for this. Generally there are three types of causes:

(1) **Initial or Initiating causes**: These are climatic as well as biotic. The former includes factors such as erosion and deposits wind,fire etc., caused by lightning or volcanic activity and the latter includes the various activities of organisms. These causes produce the bare areas or destroy the existing populations in an area.
(2) **Ecesis or continuing causes**: These are the processes as migration,ecesis,aggregation,competition,reaction etc.which cause successive waves of populations as a result of changes chiefly in the edaphic features of the area.
(3) **Stabilizing causes:** These cause the stabilizationof the community. According to Clements, climate of the area is the chief cause of the stabilization other factors of the secondary value.

Trends of succession

An ecological succession proceeds along the following four lines:

(1) A continuous change in the kind of plants and animals.
(2) A tending increase in the diversity of species.
(3) An increase in the organic matter and biomass supported by the available energy flow(but in the heterotrophic succession reverse is true).
(4) Decrease in the net community production or annual yield.

4.2.1. Types of ecological succession

The various types of succession have been grouped in different ways on the basis of different aspects. Some basic types of succession are as follows:

1. **Primary succession**: In any of the basic environment(terrestrial,fresh water,marine),a succession is primary when it starts from the primitive substratum where there was no previously any sort of living matter. The first group of organism establishing there are known as pioneer/primary community or primary colonizer.
2. **Secondary succession:** Type of succession which starts from previously built up substrata with already existing living matter. The action of any external force as a sudden change in the climatic factors, biotic intervention, fire etc. causes the existing community to disappear therefore, area becomes devoid of living matter but its substratum instead of primitive is built up sub succession are comparatively more rapid.
3. **Autogenic succession:** After the succession has begun in most of the cases,it is community itself whichas a result of its reactions with the environmentmodifies itsown environment and thus causing its own replacement by new communities. This course of succession is known as autogenic succession.
4. **Allogenic succession:** In some cases however the replacement of the existing community is caused largely by any other external condition and not by the existing organisms such a course is referredto as allogenic succession.

On the basis of successive changes in nutritional and energy contents successions are sometimes classified as:

5. **Autotrophic succession:** it is characterized by early and continued dominance of autotrophic organisms like green plants. It begins in predominantly inorganic environment and the energy flow is maintained indefinitely. There is gradual increase in the organic matter content supported by energy flow.
6. **Heterotrophic succession:** it is characterized by early dominance of heterotrophs,such as bacteria,actinomycetes,fungi and animals. It begins in a predominantly organic environment and there is progressive decline in the energy content.

In ecological literature, there are mentioned still so many other kinds of succession depending mainly upon the nature of the environment(primarily based upon moisture relations),where the process has begun,and thus it may be a **hydrosere** or **hydrarch**-starting in regions where water is plenty as ponds,lakes,streams,swamp, bog etc; a measarch-where adequate moisture are present; and a **xerosere** or **xerarch-**where moisture is present in minimal amountssuch as dry deserts, rocks etc. sometimes there are further distinguishedthe **lithosere**-initiating on rocks,**prammosere**-on sand and **halosere**-in saline water or soil.

4.2.2. Mechanisms of succession

Three types of mechanisms are involved in the succession which are as follows:

Facilitation: The organisms at a given successional stage make the environment more suitable for later successional stages. Examples: lichens breaking down rock into soil, nitrogen-fixing plants improve fertility of soil, nurse plants.

Tolerance: The organisms of a given successional stage have little impact on later successional stages. Example: Oldfield succession (possibly) species of all stages get started at the same time, but are dominant at different times because of different life histories.

Inhibition: The organisms at a given stage resist invasion by organisms of later stages. Succession proceeds when the individuals of a given stage die Example: Allelopathy.

4.2.3. Changes involved in succession

The whole process of a primary autotrophic succession is actually completed through a number of sequential steps which follow one another. These steps in sequence are as follows:

1. **Nudation**

This is the development of a bare area without any form of life. The area may develop due to several causes such as landslide,erosion, deposition or other catastrophic agent the cause of nudation may be:

1. **Topographic:** Due to soil erosion by gravity,water or wind,the existing community may disappear.Other causes may be deposition of sand etc., landslide,volcanic activity and other factors.
2. **Climatic:**Glaciers, dry period,hails and storm,frost,fire etc.may also destroy the community.

3. **Biotic:**Man is most important,responsible for destructionof forests grasslandsfor industry,agriculture,housing etc. other factors are disease epidemics due to fungi,viruses etc. which destroy the whole population.

2. Invasion

This is the successful establishment of a species in a bare area. The species actually reaches this new site from any other area. This whole process is completed in following three successive stages:

I. **Migration (dispersal):** the seeds, spores, or other propagules of the species reach the bare area.This process, known as **migration,** is generally brought about by air, water, etc.

II. **Ecesis(establishment):** after reaching to new area, the process of successful establishment of the species, as a result of adjustment with the conditions prevailing there, is known as **ecesis.** In plants, after migration, seeds or propagules germinate, seedlings grow, and adults start to reproduce. Only a few then are capable of doing this under primitive harsh conditions, and thus most then disappear. Thus as a result of ecesis, the individuals of species become established in the area.

III. **Aggregation:** after ecesis, as a result of reproduction, the individuals of the species increase in number, and they come close to each other. This process is known as aggregation.

3. Competition and coactions

After aggregation of a large number of individuals of the species at the limited place, there develops competition(inter as well as intra specific)mainly space and nutrition. Individuals of a species affect each other's life in various ways and this is called coactions. The species, if unable to compete with other species, if present, would be discarded. To withstand competition, reproductive capacity, wide ecological amplitude etc. are of much help to the species.

4. Reaction

This is the most important stage in succession. The mechanism of the modification of the environment through the influence of living organisms on it, known as **reaction**. As a result of reactions, changes take place in soil, water, light conditions, temperature etc. of the environment. Due to all these the environment is modified, becoming unsuitable for the existing community which sooner or later is replaced by another community (seral community). The whole sequence of communities that replaces one another in the given area is called a sere, and various communitiesconsisting the sere, as **seral communities, seral stages** or **developmental stages.**the pioneers are likely to have low-nutrient requirements, more dynamic and able to take minerals in comparatively more complex forms. They are small-sized and make less demand from environment.

5. Stabilization (climax)

Finally, there occurs a stage in the process, when the final terminal community becomes more or less stabilized for a longer period of time and it can maintain itself in equilibrium with theclimate of the area. This final community is not replaced, and is known as climax community and the stage of climax stage.

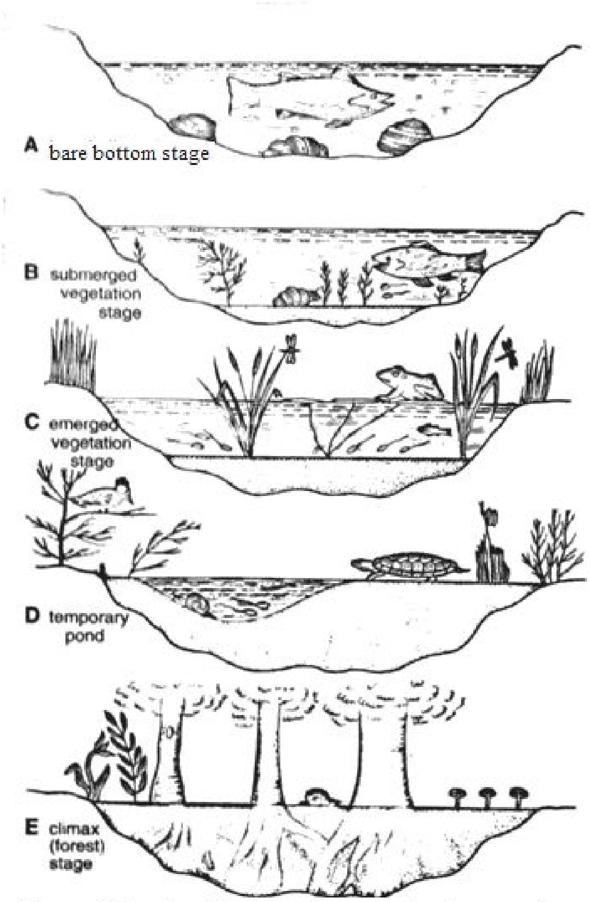


Figure. Showing Ecological succession in a pond (hydrosere) to a climax forest.

Generalized process of succession and different plant communities appearing in the process with developing environmental complex are shown in figuretaking hydrosere as a model. General process of succession as outlined above will show that the whole process involves several stages, each stage having characteristic organisms together with their environment. Each such developmental stage is called **seral stage.** These stages are infact continuous with each other and the whole sequence from beginning till the climax stage is known as **sere**. The species which colonies the bare area in the beginning of succession are called **pioneers**.

Some ecologists have talked of **retrogressive succession** in which continuous biotic influences have some degenerating influence on the process. Due to destructive effects of organisms, sometimes the development of disturbed communities does not occur and the process of succession instead of progressive becomes retrogressive. As for example forest may change to shrub by or grassland community. This is called **retrogressive succession.**

The above-mentioned general process of succession would become more clear by studying in details of the following different kinds of seres (succession) in different climatichabitat conditions:

(I) Hydrosere or hydrarch

Hydrosere originating in a pond, starts with the colonization of some phytoplanktons which form the pioneer plant community, and finally terminates into a forest, which is a climax community together with their chief components of vegetation.The various stages in the hydrosere are well studied in ponds, pools or lakes.

Just like other autotrophic successions, in a hydrosere too, successive changes take place in plants as well as animals life. But as the changes are more obvious in plants than animals it looks as it is a succession of plants only. But this is due to the fact, that changes in plants are so obvious, that we designate the community as phytoplankton stage, rooted submerged stage, etc., and so on these various stages together with their chief components of plant species of a hydrosere in a pond as shown in Figure are as follows:

1. **Phytoplankton stage:** They constitute the pioneer community. Some blue-green algae, diatoms and bacteria etc. are the first organisms to colonies the primitive medium of the pond. The soils are very much reduced with a pH value of not more than 5. They multiply and grow for some time.
2. **Rooted submerged stage:** As a result of death and decomposition of phytoplankton and their mixing with the silt, brought from the surrounding land by rain waters and by wave action of pond water,there develops a soft mud at the bottom of pond. This new habitat which tends to be a bit shallower and where light penetration may occur easily becomes now suitable for the growth of rooted submerged hydrophytes

like *Myriophyllum, Elodea, Hydrilla, Potamogeton, Vallisneria, Utricularia* etc. these plants brings about further build up of the substratum as a result of their death and decay. The water level also decreases making the pond more shallower. This new habitat now replaces these plants giving way to another type of plants which are of floating leave type.

3. **Rooted floating stage:** by now the water depth is almost 2-5 feet. These plants colonise the habitat with their rhizomes. They all are rooted hydrophytes with their large leaves floating on the water surface. These are species of *Nelumbo, Nymphaea, Limnanthemum, Aponogeton, Trapa, Monochoria* etc. some free floating species as *Azolla, Lemna, Wolffia, Pistia, Spirodella, Slavinia* etc. alos become associated with the rooted plats, due to availability of salts and other minerals in abundance. The water level by now becomes very much decreased making the pond more shallower. The decomposing organic matter formed due to death of these plants brings about further build up of the substratum. Thus floating species sooner or later disappear from the area.
4. **Reed-swamp stage:** this stage is also known as **amphibious** stage as the plants of community are rooted but most parts of their shoot (assimilatory organs) remains exposed to air. Species of *Scirpus, Typha, Sagittaria* and *Phragmites* etc. are the chief plants of this stage. They have well-developed rhizomes and form a very dense vegetation. The water level is by now very much reduced and finally becomes unsuitable for the growth of these amphibious species.
5. **Sedge- meadow stage:** due to successive decrease in water level and further changes in the substratum, species of some Cyperaceae and Gramineae,such as *Carex,Juncus, Cyperus* and *Eleochar* is colonies the area. They form mat-like vegetation towards the centre of the pond with the help of their much branched rhizomatus systems. As a result of high rate of transpiration, there is much rapid loss of water, and sooner or later the mud is exposed to air as a result of nutrients like ammonia,sulphides etc. becomes oxidized to nitrates and sulphates. Thus mosaic conditions approach the area and marshy vegetation disappears gradually and gradually.
6. **Woodland stage:** by the time of disappearance of marshy vegetation, soil becomes drier for most time of the year. This area is now invaded by terrestrial plants, which are some shrubs (*Salix,Cornus*) and trees

(*Populus, Almus*). By this time there is much accumulation of humus with rich flora of microorganisms. Thus, mineralization of the soil favours the arrival of new tree species in the area.

7. **Forest stage:** This is the climax community. The woodland community is rapidly invaded by several trees. In tropical climates with heavy rainfall, there develop tropical rain forests, whereas in temperate regions,there develop mixed forests of *Almus, Acer* and *Quercus.* In regions of moderate rainfall, there develop tropical deciduous forests or monsoon forests.

   Thus in the hydrosere, described above, stage 1 is the pioneer community, stage 7 the climax community, and stage 2 to 6 as the seral communities (seral stages).

(II) Lithosere-a Xerosere on Rock

This is a type of Xerosere originating on bare rock surfaces. The original substratum is deficient in water and lacks any organic matter, having only minerals in disintegrated unweathered state. The pioneers to colonies this primitive substratum are crustose type of lichens, and through a series of successive seral stages the successive finally terminates into a forest which constitutes to the climax community. As pointed out in hydrosere, in a lithosere also successive changes take place in both plants as well as animals. But here also as a mostof the primary autotrophic succession, changes in plants life are more obviously those in animals. The changes in plants are obviously to the extent that it looks as a succession of plants only and various stages are named on the basis of particular stage dominated by a particular plant species.

The various stages and there component plant species of a lithosere appearing on a rock are as follows:

1. **Crustose lichens stage:** As mentioned earlier, the substratum colonized by these pioneers is very poor in moisture and organic matter, subjected with extremes of temperature. The lichens of this stage are specie of *Rhizocarpon, Rinodina* and *Lecanora.* They produce some acids which bring about weathering of rocks. The dead organic matter of lichens becomes mixed with the small particles of rocks. However, this process is very slow. These lichens are then replaces by foliose of lichens.
2. **Foliose lichens stage:** They appear on the substratum partially built up by the crustose lichens. This community includes species of

Parmelia, Dermatocarpon etc. which have large leaf-like thalli. They can absorb and retain more water and are able to accumulate dust particles which help in the further build up of the substratum. Thus some humus becomes accumulate. The weathering of rocks and its mixing with humus results into the development of a fine thin soil layer on rock surface, and thus there is a change in the habitat.

3. **Moss stage:** The development of thin soil layer on rock surface especially in the crevices, favours the growth of some such xerophytic mosses as species of *Polytrichum, Tortula* and *Grimmia.* At their successful growth, they compete with the lichens. Due to their death and decay there is further additionof organic matter in the soil. The thickness of the soil layer now increases.
4. **Herbs stage:** due to more extensive growth of mosses there accumulates more soil and there are added more minerals to it due to leaching out from the overlying vegetation. This changed habitat favours the growth of some herbaceous weeds which are chiefly the annuals, in turn being followed by some biennials and perennials. Due to their growth and death there is much more accumulation of humus in soil togetherwith further weathering of rock. Thus, habitat changes with decreasing xeric conditions.this stage is constituted by such shallow rooted grasses as *Aristida,Festucs,poa,solidago,*etc., which in turn are replaced by shrubs.
5. **Shrub stage:** due to much accumulation of soil the habitat becomes suitable for shrubs which start migrating in the area. These are species of *Rhus, Phytocarpos,* etc. They over shadow the herbaceous vegetation. The soil is further enriched by this dense shurby growth. These inturn and finally replaced by trees which make up the climax community.
6. **Forest stage:** some xerophytes tree species invade the area. Further weathering of rocks and increasing humus contain of the soil favour the arrival of more trees and vegetation finally becomes mesophytic. Thus, these develops finally a forest community.

Heterotrophic (Microbial) Succession

Succession of microorganisms like fungi, bacteria, actinomycetes etc.That occurs within a microhabitat (microenvironment or microclimate), has been variously called as **microsuccession**, **serule or microsere.** This type of succession, which is heterotrophic in nature, begins on a habitat, which in contrast with that of autotrophic succession is rich in organic matter content. It follows the course of an **autogenic succession,** i.e. determined in part by the organisms themselves. However, most of such succession involves the opposite progression, from initial conditions of high energy content to final stage of nil energy. The substratum here, instead of being progressively complex (as happensin autotrophic successions) becomes gradually and gradually depleted in terms of organic matter content. Such successions of micro organisms play an important role in ecosystems, where the decomposers are an important biotic component. These bring about mineralization of dead organic matter making the mineral elements again available to soils. In the succession of fungi on plant remains in the soil (roots etc. dying through natural senescence), the primary colonizers are likely to be weak parasites and/or saprophytes of sugar fungi group. On dead tissues, the ascomycetes and their imperfect forms (cellulose decomposers) are the secondary colonizers. At this stage, some mucorales may also appear as secondary saprophytic sugar fungi. Finally, the basidiomycetes (lignin decomposers) appear in the succession. The chemical make-up of the substrate determines the qualitative characteristics of fungal flora appearing at a particular stage of decomposition.

4.2.4. Concept of climax

The final, terminal and more or less stabilized community in succession that is able to establish some sort of equilibrium with the environmental conditions of that area was termed climax by Clements (1916). The subject of climax has been much controversial and is reviewed from time to time by many ecologists. According to Clements (1916,1935), climax has the following three principal characteristics:

1. **Unity:** climax in a unity, and index of the climate of area. Life or growth from forms of plants indicates the climate type. Unless all the species are not taken as an organized unit, climax would not indicate the climate.
2. **Stability:** the form of climax community is more or less stable with the climate. This climax community cannot be replaced through competition any other group of species. In other words, according to Clements, in a particular climate are there may develop climax communities only with a few characteristics dominating species.
3. **Origin and phylogenetic gap relations:** climax community is to be treated equivalent to an organism like which it take worth, grows and develops and become mature. In this organismic-concept of climax

community, Clements went to extend of designating a super organism. In any climatic region, the developmental stages of the climax community have their own characteristic, which reflects the type of climate. Similar to the development of organism with changing age, climax community have also simultaneously undergone changes with changing climate. Thus phylogenetic relations may be established between different climax community of the World.

There have been put three popular theories about the climax concept in ecology.

[I] MonoclimaxTheory

As evident from the above account, F.E.Clements emphasized the importance of only climate in the stabilization of the climax community. According to the monoclimax theory, within a given region all land surfaces eventually tend to be occupied by a single kind of community which is climax. The climaxes determine by the single factor that is regional climate.

[II] Polyclimax Theory

According to Tansley climax is controlled by many (and not one-climate) factors,concept became popularly known as **polyclimax theory**. Clements, although agreed with the possible control of factors other than climate on climax, but he thought that these communities would sooner or later develop into climatic-climax types. Consequently, with an attempt to accommodate these stages in his own hypothesis, Clements introduced in literature a number of new terms. These are as follows:

The stage in succession just preceeding the climate climax community was called a **sub-climax.** The community, which became stabilized at any of the seral stages of succession due to microclimate, or effects of factors as soil, fire etc. was called as **Sereclimax.**

The only way to come out of the jargons of Clements terminology was the polyclimax theory (Tansley, 1935, 1939). There is evidence that even under primeval conditions it was difficult to find large areas of uniform vegetation. According to this theory the climax stage may be controlled by any factor of the environment and not only by climate, accordingly, the climax stage is to be named, depending upon the nature of the factor in stabilization. Thus, in addition to climatic climax, controlled by climate, there may develop:

1. **Edaphic climax:** on an underdeveloped soil, it develops due to edaphic effect.

2. **Biotic climax:** developed due to biotic disturbances. (due to grazingeffects) and **Zootic climax**(due to animils).
3. **Topographic climax:** due to differences in topographic factors at mountains, hills, mounds etc.
4. **Fire climax:** due to repeated effects of fire.

According to Daubenmire (1968), if one accepts monoclimax theory, it means to admit that other factors of the environment are of secondary value.

4.3 Structure and function of ecosystem

The term ecosystem was proposed by A.G. Tansley in1935. There are many other parallelterms or synonyms for the ecosystem which have been proposed by various ecologists, e.g., biocoenonsis (Karl Mobius, 1877), microcosm (S.A. Forbes, 1887), holocoen(Friederichs, 1930), bio system (Thienemann, 1939), geobiocoenosis (Sukhachev.1944). bioenert body (ernadsky, 1944) and ecosom, etc. In recent years, ecological studies of ecosystems undertake besides structure, the similarities and differences in food and energy relationships among living components of ecosystem. This is called bioenergetic approach of modern ecology.

Kinds of ecosystem

An ecosystem can be natural orartificial temporary orpermanentandlargeortiny,thusvarious constituent ecosystems of the biosphere fall into the following categories: ecosystems. Based upon the particular kind of habitat, these are further classified as Terrestrial ecosystems such as forests, grasslands, deserts etc.Aquatic ecosystems which may be further distinguished as follows: Fresh water ecosystems These may be lotic (running waterax spring, brook, stream or river) orlentic(standing water as lake, pond, pool puddle ditch etc. Marine ecosystems include sallow water bodies which may be deep bodies as an ocean or shallow ones as a sea or estuary. Artificial ecosystems also called man-made or man-engineered ecosystems. These are maintained artificially by man where, by addition of energy and planned manipulations, natural balance is disturbed regularly, eg croplands such as sugarcane, maize, wheat, Rice-fields orchards gardens, villages, cities, dams, aquarium and manned spaceship.

Structure of ecosystem

The structure of an ecosystem is basically a description of the species of organism that are present including information on their life histories, populations and distribution in space. It also includes descriptive information on the non-living (physical) features of environment, including the amount and distribution of nutrients. An ecosystem has two major components:

I.Abiotic or Non-living Components

Climatic abiotic component of the ecosystem comprises of (i) physical condition such as air, water, soil, light duration and intensity,moisture,substances such as carbon (C), nitrogen (N), sulphur (S), phosphorus (P) and so on, all of which are involved in cycling of materials in the ecosystem (i.e. biogeochemical cycles). The amount of these inorganic substances present at any given time in an ecosystem is designated as the standing state or standing quality. (ii) amount and distribution of inorganic chemicals such as chlorophylls etc. and organic substances such as proteins, carbohydrates, lipids, humic substances, etc.present either in the biomass or in the environmenti.e. biochemical structure that link the biotic and abiotic components of the ecosystem.(iii) the climate of given region.

II. Biotic or Living Components

In the trophic structure of any ecosystem, where living organisms are distinguished on the basis of their nutritional relationships, which are discussed as follows:

1. Autotrophic component. Autotrophiccomponent of ecosystem includes the producers or which convert solar energy into chemical energy(that becomes locked in complex organic substances such as carbohydrate, lipid, protein, etc.) with the help of simple inorganic substances such as water and carbon dioxide and organic substances such as enzymes. Autotrophs include green plants, grasses, algae, tiny phytoplanktons and photosynthetic bacteria and cyanobacteria blue green algae having photosynthetic pigment chlorophyll to transduct the solar or light energy of sun.

2. Heterotrophic component. In the heterotrophic (hetero- other; trophic- nourishing) organisms predominate the activities of utilization, rearrangement and decomposition of complex organic materials. Heterotrophic organisms are also called consumers, as they consume the matter built up by the producers(autotrophs). The consumers are of following two main types:

(a) Macroconsumers: These are also called phagotrophs (phago- to eat) and include mainly animals which ingest other organisms or chunks of organic Depending on their food habits, consumers may either be herbivores (plant eaters) or carnivores (flesh eaters) herbivores live onliving plants and are also known as primary consumers, e.g., insects, zooplanktons and animals such as deer, cattle, elephant etc. Secondary and tertiary consumers if present in food chain of an ecosystem, are carnivores or omnivores, e.g., insects such as preying mantis, dragon flies and large animals such as tiger, lion, leopard, wolf, etc.Secondary consumers are the carnivores which feed on primary consumers or herbivores. Carnivores are, often, recognized as carnivore order-1(C_1), carnivore order-2(C_2) and so on, depending on their food habits. Ticks and mites, leeches and blood-sucking insects(mosquito, bed-bug) are dependent on herbivores, carnivores and omnivores.

(b) Microconsumers. These are also called decomposers, reducers, saprotrophs(sapro= decompose), osmotrophs(osmo= to pass through a membrane) and scavengers. Microconsumers include microorganisms such as bacteria, actinomycetesand fungi. Microconsumers breakdown complex organic compounds of dead or living protoplasm, absorb some of the decomposition or breakdown products and release inorganic nutrients in the environment, making them available again to autotrophs or producers. Some invertebrate animals such as protozoa, oligochaeta such as earthworms, etc., use the dead organic matter for their food, as they have the essential enzymes and hence, can be classified as decomposer organisms. Some ecologists believe that microorganisms are primary decomposers, while invertebrates are secondary decomposers.

The disintegrating dead organic matter is also known organic detritus (Latin worddeterere means to wear away). By the action of detritivores the disintegrating detritus result into particulate organic matter (POM) anddissolved organic matter (DOM) which play important role in the maintenance of the edaphic environment.

Functions of an ecosystem

When we consider the function of an ecosystem, we must describe the flow of energy and the cycling of nutrients. That is, we are interested in things like how much sunlight is trapped by plants in a year, how much plant material is eaten by herbivores, and how many herbivores are eaten by carnivores. Thus, the producers, the green plants, fix radiant energy and with the help of minerals(such as C, H,O, N, P, Ca. Mg, Zn, Fe, etc)taken from theiredaphic (soil) or aerial environment(the nutrient pool) they build up complex organic matter (carbohydrates, fats, proteins, nucleic acids, etc.).

The green plantsare known as converters or transducers, as green plants produce carbohydrates and not energy and since they convert or transduce radiant energy into chemical form, they must be better called converters or transducers. The two ecological processes of energy flow and mineral cycling involving interaction between the physicochemical environment and the biotic communities may be considered the 'heart' of ecosystem dynamics. In an ecosystem, energy flows in non-cyclic manner(unidirectional) from sun to the decomposers via producers and macroconsumers(herbivores and carnivores), whereas the minerals keep on moving in a cyclic manner. Detailed about energy flow and mineral cycling are discussed below separately.

4.4 Energy flow and mineral cycling

Concept of energy: Energy is the capacity to do work. Biological activities require consumption of energy which ultimately comes from the sun, Radiant energy of sun(or solar energy) is transformed into chemical energy by the process of photosynthesis this is stored in plant tissues and then transformed into mechanical and heat form of energy during metabolic activities. In the biological world, the energy flows from the sun to plants and then to all heterotrophic organisms, such as microorganisms, animals and man in the following manner:

Mechanical energy has two forms, namely kinetic or free energy and potential energy. The energy a body possess by virtue of its motion is called kinetic energy and is measured by the amount of work done in bringing the body at rest. Potential energy is stored energy (the energy at rest) and becomes useful after conversion into kinetic energy. All organisms require a source of potential energy, which is found in the chemical energy of food. The oxidation of food releases energy which is used to do work. Thus, chemical energy is converted into mechanical energy. Food means material containing energy that organism can use. Food is the means to transfer of both matter and energy in the living world. Plants synthesize food with the help of solar energy and inorganic substances such as nutrients, CO_2 and H_2O in a biochemical process called photosynthesis.

2. Unit of energy: The unit of measurement of energy is erg; the work done in lifting 1 gram of weight to a height of l cm against the force of gravity is equal to 981 ergs. One crore ergs (10 ergs) is equal to one Joule. All forms of energy can be completely converted into heat energy. For a better and uniform expression in ecology, therefore, energy is measured not in terms of ergs but joules or units of heat measurement. Heat is measured in calories. One calorie is equal to the heat energy required to raise the temperature of 1 gram of water from 14.5 C to 15.5°C, and one calorie is equal to 4.2 joules or 4.2x 107 ergs. One thousand calories (l0) makes one kilo calories or a kilogram calories (Kcal or Call. Now, there is a trend of expressing energy in ecological literature in terms of kilojoules.

3. Ecological energetic: Ecological energetics includes energy transformation which occurs within ecosystems. In ecological energetics, we consider (i)quantity of energy reaching an ecosystem per unit of area (say a square metre) per unit of time (say one hour, day or year); (ii) quantity of energy trapped by green plants and converted to a chemical form (photosynthesis) and (iii) the quantity and path of energy flow from green plants to organisms of different trophic levels over a period of time in a known area (i.e., energy flow from producers to consumers).

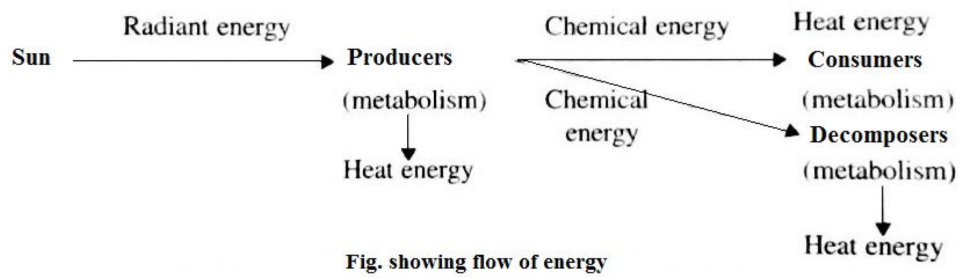


Fig. showing flow of energy

The energy used for all plant life processes is derived from solar radiations. A fraction, i.e., about 1/50 millionth of the total solar radiation reaches the earth's atmosphere. Solar radiation travels through the space in the form of waves, their wavelength ranging from 0.03 A0 to several kilometres. While most radiations are lost in space, those ranging from 300 mμ to 10 mμ and above 1 cm (radiowaves) enter the earth's outer atmosphere (which is about 28 km altitude). The energy reaching the earth's surface consists mainly of visible light (390-760 mμ) and infrared component. On clear day radiant energy reaching the earth's surface is about 10% UV, 45% visible and 45% infra-red. Green plants absorb strongly the blue and red light (400 to 500 mμ and 600 to 700 mμ respectively).

About 34% of the sunlight reaching the earth's atmosphere is reflected back by clouds and dust, 10% is held by ozone layer, water vapour and other atmospheric gases. The rest, 56% reaches the earth's surface. Only a fraction of the energy reaching earth's surface (1 to 5%) is used by green plants for photosynthesis and rest is absorbed as heat by ground vegetation or water. In fact, only about 0.02% of the sunlight reaching the atmosphere is used in the process of photosynthesis. The amount of radiant energy of all wavelengths that cross unit area per unit time is called solar flux. The solar flux is about 8.368 J (2 cal)/cm2 min. At a given place, it varies diurnally because of the earth's rotation on its axis.

4. Laws governing energy transformation: Energy transformation in ecosystems can also be explained in relation to the laws of thermodynamics, which are usefully applied to closed systems. The **first law of thermodynamics** is the law of conservation of energy, which says that energy may be transformed from one form into another but is neither created nor destroyed. If an increase or decrease occurs in the internal energy (E) of the system itself, work (W) is done and heat (Q) is either evolved or absorbed. Thus,

$$\Delta E = W + Q$$

Decrease in internal energy Work done by the system Heat given off by system of the system

(Δ = change in quantity)

The total amount of heat produced or absorbed in a chemical reaction, either occurring directly or in stages, always remains the same. This is called the specific law of constant heat sums and included in the first law.

This law explains the interconvertibility of all forms of energy but does not refer to the efficiency of transformation or conversion. In ecological systems solar energy is converted into chemical energy transformation stored in food materials which is ultimately converted into mechanical and heat energy. Thus, in ecological systems, the energy is neither created nor destroyed but is converted from one form into another. Thus, when wood is burned the potential energy present in the molecules equals the kinetic energy released, and heat is evolved to the surroundings this is an exothermic reaction. In an endothermic reaction, energy from the surrounding may be consumed into a reaction. For example, in photosynthesis, the molecules of the products store more energy than the reactants. The extra energy is acquired from the sunlight, but even then there is no gain or loss in total energy. The **second law of thermodynamic** states that processes involving energy transformation will not occur spontaneously unless there is degradation of energy from a non-random to a random form. In manmade machines (closed systems), heat is the simplest and most familiar medium of energy transfer. But in biological systems, it is not a useful medium of energy transfer, as living systems are essentially isothermal and there are no significant differences in temperature between different parts of a cell or between different cells in a tissue.

5. Concept of free energy, enthalpy and entropy: free energy is that component of the total energy of a system which can do work under isothermal conditions. All physical and chemical processes proceed with a decline in free energy until they reach an equilibrium where the free energy of the system is at a minimum.

$$\Delta G - \Delta H - T\Delta S$$

Where, ΔG= Change in the free energy of the system

ΔH= Change in enthalpy (a change in the amount of energy in the form of heat liberated or absorbed by the system during physical or chemical changes)

ΔS= Entropy change of the system (Entropy is the name of a quantity in thermodynamics representing the degree of disorder in a physical system or the extent to which the energy in a system is available for doing work).

T= Absolute temperature

thus, decline in G is accompanied by an increase in TΔS. These are equal if there is no heat transfer between the system and the surrounding. If a reaction proceeds with a decline in free energy, we call it spontaneous.

6. Maintenance cost of secondary producers: in general, 55 to 75% of the assimilated energy is spent on maintenance of secondary producers. Temperature, moister conditions of the habitat and the types of species determine the maintenance cost.

7. Assimilated energy and respiration: Once food is eaten, its energy follows a variety of paths through the organisms (i.e. digestion, respiration, growth and reproduction etc.). Regardless of an organism's source of food, what it digests and absorbs is referred to as assimilated energy, which support maintenance, builds tissues, or is excreted in unusual metabolic byproducts. The energy used to fulfil metabolic needs, most of which is lost as heat, is known as respired energy.

8. Ecological efficiency: It is the product of efficiencies with which organisms exploit their food resources and transform them into biomass which becomes available to the next higher trophic level. Because most biological production is consumed, exploitation efficiency is 100 percent overall, and ecological efficiencydepends upon two factors: the proportion of assimilated energy incorporated in growth, storage and reproduction. The first proportion is called assimilation efficiency and second, the net production efficiency. The product of the assimilation and net production efficiencies is the gross production efficiency: The proportion of food energy that is transformed into consumer biomass energy.

Definition of various energetic efficiencies are given below:

$$1. Exploitation\ efficiency = \frac{Ingestion\ of\ food}{Prey\ production}$$

$$2. Assimilation\ efficiency = \frac{Assimilation}{Ingestion}$$

$$3. Net\ production\ efficiency = \frac{Production\ (growth\ and\ reproduction)}{Assimilation}$$

$$4. Gross\ production\ efficiency = (2) \times (3) = \frac{Production}{Ingestion}$$

$$5. Ecological\ efficiency = (1) \times (2) \times (3) = \frac{Consumer\ production}{Prey\ production}$$

Mineral cycling

1. The carbon cycle

The carbon being the basic constituent of all organic compounds and a major element involves involved in the fixation of energy by photosynthesis, is so closely tied to energy flow that the two are inseparable. The source of all the fixed carbon both in living organism and fossil deposits is carbon dioxide CO_2, found in the atmosphere and the dissolved in the waters of the earth. During photosynthesis, carbon from atmospheric CO_2 is incorporated into the production of the carbohydrates, glucose, $C_6H_{12}O_6$, the subsequently may be converted to another organic compounds such as polysaccharides (sucrose, starch, cellulose,etc.) protein and lipids. All the polymeric organic compounds containing carbon are stored in different plants-tissues as food and from then the carbon is passed on to the tropic level of herbivores or heights of parasites or retained by the plant until it serves as food for decay organism (viz., decomposers). Some of the carbon is returned to the atmosphere (or the enveloping aqueous medium) in the form of CO_2 a by-product of plant respiration, in which, a considerable portion of the glucose is oxidized to yield CO_2, H_2O and energy as follows:

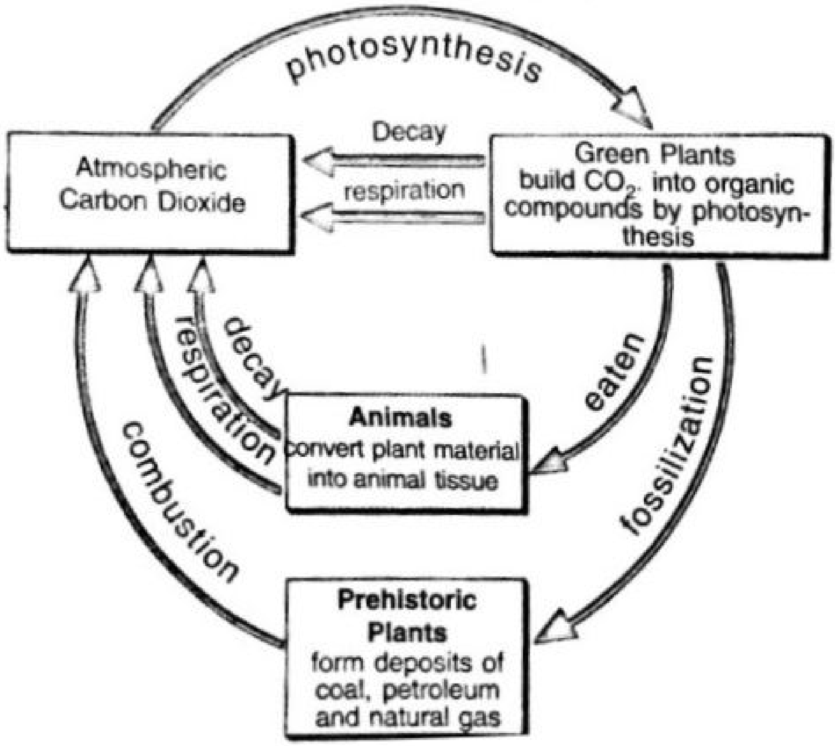
$$1/6C_6H_{12}O_6 + O_2 \longrightarrow CO_2 + H_2O + \text{Energy}$$

The CO_2 which is released as the by-product by herbivores or phytoparasites may travel a number of routes. It may be incorporated into protoplasm (assimilation) and stored until the organism dies, where upon it is utilized by decomposers; it may be released through animal respiration; it may serve as live food for other organisms; or finally it may be stored in the environment as CO_2. Similar fates await carbon at the carnivore trophic levels. In fact, all the carbon of plants, herbivores, carnivores and decomposers is not respired by some is fermented and some is stored. The carbon compounds that are lost to the food chain after fermentation, such as methane, are readily oxidized to carbon dioxide by inorganic reactions in the atmosphere. As for the storage of carbon in sediments, just as deposition works to store materials, erosion may uncover them, and inorganic chemical weathering of rock can oxidized the carbon contained there. Some carbon is permanently stored in the sediments and not uncovered by weathering; it may be replaced by carbon dioxide released by volcanoes and other similar examples of intense geological activity. In modern age, man has greatly increased the rate at which carbon is passing from sedimentary form to carbon dioxide. The combustion of fossil fuels is a significant means of recycling sedimentary carbon much faster than natural weathering.

Small portion of carbon, especially in the sea, is found not as organically fixed carbon, but as carbonate (CO_3^-), especially calcium carbonate ($CaCO_3$). $CaCO_3$ is very commonly used for shell construction by such animals as clams, oysters, some protozoa, and some algae. Carbon dioxide reacts with water to form carbonate in the following three step reaction.

The precise amount of each of these constituents in the water depends on the pH of the water. Organisms such as clams can combine bicarbonate or carbonate with calcium dissolved in the water to produce calcium carbonate. After the death of the animal, this calcium carbonate may either dissolve or remain in sedimentary form.

Certain control mechanisms are inherent in the carbon cycle. The rate of carbon utilization is dependent on its availability. If excessive amounts of carbon are taken up in any one phase of the cycle, other phases of activity may be inhibited or slowed down. For example, if the pH of water is alkaline, more carbon is tied up in a carbonate and less is in solution. This removal of carbon in solution would upset the equilibrium established between the atmospheric and the dissolved CO_2 and the net effect would be a movement of CO_2 into solution until the equilibrium was reached.



The Carbon Cycle

Peculiarities of carbon cycle

Through carbon-cycle exhibits basic similarity with other biogeochemical cycles, yet it is usual in that the organic phase is not essentially a complete cycle within itself. The organic (biotic) and atmospheric (abiotic) phases, however, are so closely interwined that the rapid cycling typical of the organic phase is present. The multiplicity of paths along which carbon can flow is typical of biogeochemical cycles is general, and provides a well-buffered system with adequate feedback mechanisms to insure an adequate supply of the carbon. It is significant that all phases of the cycle yield carbon dioxide at some time, and carbon dioxide is the raw material for them. Thus, despite its relative low concentration in the atmosphere (0.03 per cent), carbon in a form in which it can be used by living organisms is virtually always present.

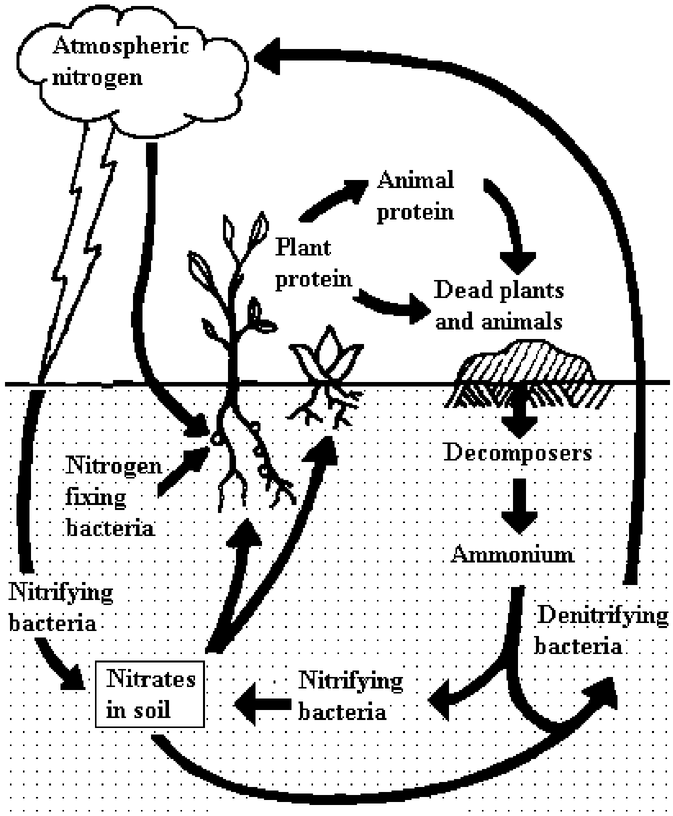
2. The nitrogen cycle

Nitrogen is an essential constituent of different biologically significant organic molecules such as amino acids and proteins, pigments, nucleic acids and vitamins. It is also the major constituent of the atmosphere, comprising about 79 per cent of it. The paradox is that in its gaseous state, N_2 is abundant but is unavailable to most life. Before it can be utilized it must be converted to some chemically usable form.

To be used biologically, the free molecular nitrogen has to be fixed and fixation requires an input of energy. In the first step molecular nitrogen (N_2 has to be split into two atoms: $N_2 \longrightarrow 2N$). The free nitrogen atoms then must be combined with hydrogen to form ammonia, with the release of some energy:

$$2N+3H_2 \longrightarrow 2NH_3$$

The fixation comes about in two ways. One is by high energy fixation such as cosmetic radiation, and hydrogen of water. The resulting ammonia and nitrates are carried to the earth in the rain water. The second method of nitrogen fixation which contributes about 90 per cent of fixed nitrogen of earth is biological. Some bacteria, fungi, and blue-green algae can extract molecular nitrogen from the atmosphere and combine it with hydrogen to form ammonia. Some of this ammonia is excreted by the nitrogen-fixing organism, and thus, becomes directly available to other autotrophs. Some of these nitrogen-fixing organisms may be free-living, either in the soil (e.g., bacteria – *Azotobacter* and *Clostridium*) or in water (e.g., blue-green algae – *Nostoc, Calothrix* and *Anabaena*) and produce vast quantities of fixed nitrogen. In other cases, certain symbiotic bacteria of genus *Rhizobium*, although unable to fix atmospheric nitrogen themselves, can do this when in combination with cells either from the root of legumes (e.g, peas, beans, cloves and alfala) and of other angiosperms such as *Alnus, Ceanothus, Shepherdia, Elaeagnus* and *Myrica*, or form the leaves of African genera of Rubiaceae and Pavetta. The bacteria invade the roots or leaves and stimulate the formation of root-nodules or leaf nodules, a sort of harmless tumor. The combination of symbiotic bacteria and host cells remains able to fix atmospheric nitrogen and for this reason legumes are often planted to restore soil fertility by increasing the content of fixed nitrogen. Nodule bacteria may fix as such as 50 to 100 kilograms of nitrogen per acre per year, and free soil bacteria as ,much as 12 kilograms of per acre per year. Further both free soil bacteria symbiotic bacteria (*Azotobacter* and *Clostridium*) produce ammonia as the first stable product and like the symbiotic bacteria, they require molybdenum as an activator and are inhibited by an accumulation of nitrates and ammonia in soil.



NITROGEN CYCLE

Recently, certain lichens (*Collema tunaeforme* and *Peltigera rufescens*) were also implicated in nitrogen fixation (Henriksson, 1971). Lichens with nitrogen-fixing ability possess nitrogen-fixing blue green species as their algal component.

Nitrogen fixed by symbiotic and non-symbiotic microorganisms in soil and water is one source of nitrogen. Another source is organic matter. The nitrogenous wastes and carrion of animals are degraded by the detritus organisms, nitrogen is converted to the amino form (e.g., L-Alanine).the amino group ($-NH_2$) is liberated from organic molecules to form ammonia; this process is called deamination. Certain specific bacteria, most notably of the genus Nitrosomonas, can oxidize ammonia to nitrite (NO_2) by the reaction.

$$2NH_3+3O_2 \longrightarrow 2NO_2^- + 2H_2O+2H^+$$

This reaction takes place in the soil, in lake or sea water or sediments, and whenever ammonia is being released and oxygen is present. As fast as nitrite is produced, other bacteria, such as Nitrobacter, can combine nitrite with oxygen to form nitrite (NO_3) by the reaction:

$$2NO_2\text{-}+O_2 \longrightarrow 2NO_3$$

Both of these reactions which are performed by two nitrifying bacteria— Nitrosomonas and Nitrobacter are the parts of a single biological process called nitrification. In nitrification process, thus, ammonia is oxidized to nitrate and nitrite yielding energy. This energy is used by the bacteria to make their organic materials.

3. The Phosphorus Cycle

On the scale of the biosphere, the phosphorus cycle is incomplete or open. Like the other elements of biogeochemical cycles, phosphorus exists in the mineral and organic form. The stored mineral phosphorus available to biocenoses is entirely contained in the rocks. It is found in the lithosphere in apatites or fossilized sediments such as phosphorites This relatively rare element in the biosphere has a cycle that has two phases: one that acts in terrestrial ecosystems, the other in aquatic ecosystems phosphorus circulates in biocenoses through the food webs. It is first absorbed by plants and then incorporated in herbivores, carnivores, parasites, predators and finally decomposers. When living things die, micro-organisms mineralize the organic phosphorus molecules into phosphates. Some of these may be newly absorbed by plants and keep up a more or less complete cycle on land. But most phosphate ions are leached and run off into the aquatic ecosystems.

Phosphorus in terrestrial ecosystems: The dissolution of phosphate rocks makes mineral carbon available to plant roots, which they can absorb and incorporate in their biomass. Phosphorus is a major element in the metabolism of living things. It is especially involved in the constitution of essential molecules involved in the major functions of organisms. It is involved in the elaboration of tissues (nervous system, skeleton) and controls heredity and energy transport.

Above all, phosphorus is found in the nucleic acids DNA and the RNAs, in the phospholipids of the mem- branes and the brain, in the energy-rich molecules ATP, ADP, and AMP, and associated with sugars, glucose 6 phosphate, ribulose diphosphate, and other molecules.

Phosphorus in aquatic ecosystems Because of run-oft, there are dissolved phosphates(PO, in Iresh water and in the oceans. Phytoplankton captures and uses them in their development. In normal conditions, the phosphorus is insufficient to ensure optimal photosynthesis ol algae and their development is rather limited. Sometimes, on the other hand, because of human activities, there is excessive phosphorus in the water. The disturbance of the N/P ratio leads to an abnormal proliferation of certain algae or bacteria and eutrophication of waters.

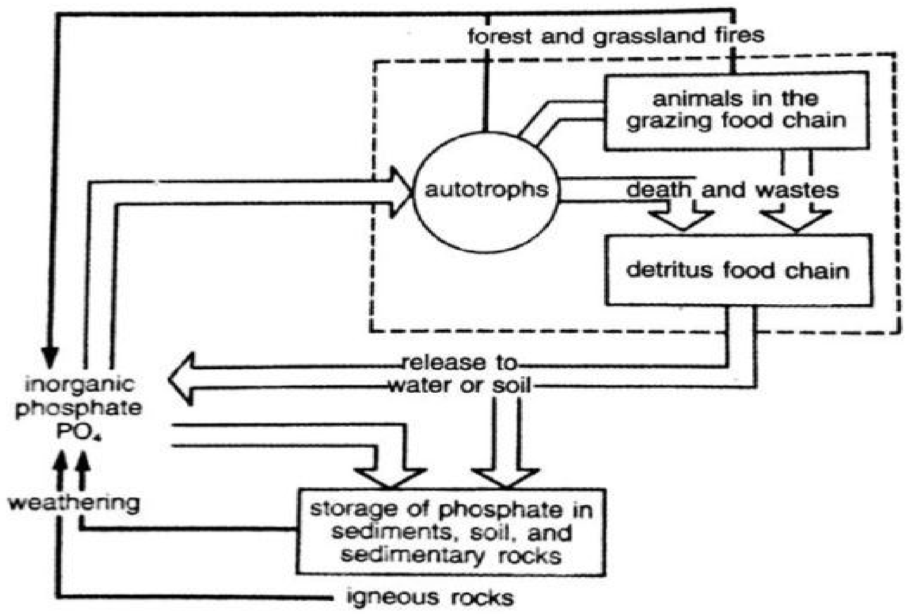


Fig. Phosphorus cycle

As in the continental biosphere, mineral phosphorus captured by the algae is incorporated in the organic form in aquatic food webs. It passes from the molluscs, to zooplankton, then concentrates in small part of fish, mammals, and birds. A land because the phosphorus in oceans returns to the of fishing or through the excrement of aquatic birds. Fish are one source of high amounts of phosphorus. As for bird excrement, it is collected trom the rock cliffs on which the birds build their nests, especially in Chile, and used as guano, a phosphate fertilizer

Another part, mineralized in the form of sediments from cadavers of aquatic creatures and accumulated in shallow water, rises by the phenomenon of upwelling(ascending currents). It can also be incorporated in the food webs by phytoplankton and thus goes through a closed cycle. But the greatest quantity of this mineralized phosphorus is lost in very deep sediments. It thus escapes cycling and presents the open part of the phosphorus cycle. It ultimately fossilizes in the form of phosphate rocks within the oceanic plates.

4.5 Primary production and decomposition

The productivity of an ecosystem refers to the rate of production, i.e., the amount of organic matter accumulated in any unit time. It is of following types:

1. **Primary productivity**. It is defined as the rate at which radiant energy is stored by photosynthetic and chemosynthetic activity of producers. Primary productivity is of following types:

   (i) Gross primary productivity: It refers to the total rate of photosynthesis including the organic matter used up in respiration during the measurement period. GPP depends on the chlorophyll content. The rate of primary productivity are estimated intermsofeitherchlorophyll content as chl/gdry weight/ unit area or photosynthetic number, i.e., amount of CO_2, fixed/g chl/hour.

   (ii) Net primary productivity. It is the rate of storage of organic matter in plant tissues in excess of the respiratory utilization by plants during the measurement period. Primary production is measured by following methods- harvest method, oxygen measurement method (or light or dark method), oxygen diurnal curve method, carbon dioxide measurement method (enclosure method), the aerodynamic method, the pH method, radioisotope method, chlorophyll estimation method.

2. **Secondary productivity**. It is the rate of energy storage at consumer's levels i.e. herbivores, carnivores and decomposers. Consumers tend to utilise already produced food materials in their respiration and also convert the food matter to different tissues by an overall process. So, secondary productivity is not divided into"gross' and'net' amounts. Due to this fact some ecologists such as Odum(1971), prefer to use the term assimilation rather than production at this level the consumers level. Secondary productivity, in fact, remains mobile(i.e., keeps on moving from one organism to another) and does not live in situ like the primary productivity.

3. **Net productivity.** It is the rate of storage of organic matter not used by the heterotrophs or consumers, i.e., equivalent to net primary production minus consumption by the heterotrophs during the unit period as a season or year, etc.

Food chains in Ecosystems

In an ecosystem one can observe the transfer or flow of energy from one trophic level to other in succession. A trophic level can be defined as the number of links by which it is separated from the producer, or as the Nth position of the organism in the food chain. The patterns of eating and being eaten forms a linear chain called **food chain** which can always be traced back to the producers. Thus, primary producers trap radiant energy of sun and transfer that to chemical or potential energy of organic compounds such as carbohydrates, proteins and fats. When a herbivore animal eats a plant(or when bacteria decompose it) and these organic compounds are oxidized, the energy liberated is just equal to the amount of energy used in synthesizing the substances(first law of thermo dynamics), but some of the energy is heat and not useful energy(second law of thermodynamics). If this animal, in turn is eaten by another one, along with transfer of energy from a herbivore to carnivore a further decrease in useful energy occurs as the second animal(carnivore) oxidizes the organic substances of the first(herbivore or omnivore) to liberate energy to synthesize its own cellular constituents. Such transfer of energy from organism to organism sustains the ecosystem and when energy is transferred from individual to individual in a particular community, as in a pond or a lake or a river, we come across the food chains. The numbers of steps in a food chain are always restricted to four or five, since the energy available decreases with each step. For example, in a typical food chain of an Indian river, a diatom may be eaten by a copepod which is eaten by a small fish, which forms the food source of large fish and so on.

Inasimple food chainout of 1000 calories of energy reaching a plant only 10 calories (1% are stored by the plant. The remaining calories of energy(99%) are lost to the environment or for plants own maintenance. of the 10 calories which are available to the herbivore, 9 calories (99%) are lost at its level and only 1 calorie is passed down to the carnivore. Thus, at each trophic level in a food chain, a large portion of energy is used for its own maintenance and ultimately lost as heat. Consequently, organisms in each trophic level pass on less and less energy than they receive. This tends to limit the number of steps or trophic levels to four or five. The longer the food chain, the less is the energy available to the final member. In nature, basically two types of food chains are recognized- grazing food chain and detritus food chain.

1. **Grazing food chain.** This type of food chain starts from the living green plants, goes to grazing herbivores and on to the carnivores.

Ecosystems with such type of food chain are directly dependent on an influx of solar radiation. Thus, this type of food chain depends on autotrophic energy capture and the movement of this energy to herbivores. Most of the ecosystems in nature follow this type of food chain. These chains are very significant from energy standpoint. The phytoplanktons ⟶ zooplanktons ⟶ fish sequence or the grasses ⟶ rabbit ⟶ fox sequence, are the examples of grazing food chain. Further the producer ⟶ herbivore⟶ carnivore chain is a predator chain. Parasitic chains also exist wherein smaller organisms consume larger ones without outright killing as the case of the predators.

2. **Detritus food chain.** The organic wastes, exudates and dead matter derived from the grazing food chain are generally termed detritus. The energy contained in this detritus in not lost to the ecosystem as a whole: rather it serves as the source of energy for a group of organisms(detritivores that are separate from the grazing food chain, and generally termed as the detritus food chain). The detritus food chain represents an exceedingly important component in the energy flow of anecosystem.Indeedin some ecosystems, considerably more energy flows through the detritus food chain than through the grazing food chain. In the detritus food chain the energy flow remains as a continuous passage rather than as a stepwise flow between discrete entities. The organisms of the detritus food chain are many and include algae, bacteria, slime molds, actinomycetes, fungi. Protozoa, insects, mites, Crustacea, centipedes, molluscs, rotifers, annelid worms, nematodes and some vertebrates. Some species are highly specific in their food requirements and some can eat almost anything. Many Protozoa, for instance, need certain specific organic acids, vitamins, and other nutrients before they can thrive; on the other hand, the guts of small Collembola(a group of tiny soil insects) have been reported to contain decaying plant material,fungal fragments, spores, fly, pupas, other Collembola, parts of decaying earthworms, and cuticle from their own faecal casting. In contrast to the grazing food chain, in which energy storage is entirely within the tissues of living organisms, energy storage for the detritus food chain may be largely external to the organisms, and in the detritus itself.

Significance of food chain: The food chains studies help understand the feeding relationships and the interaction between organisms in any ecosystem. They also help us to appreciate the energy flow mechanism and matter circulation in ecosystem, and understand the movement of toxic substances in the ecosystem and the problem of biological magnification(e.g., DDT).

Food web

In nature simple food chains occur rarely. The same organism may operate in the ecosystem at more than one trophic level, i.e. it may derive its food from more than one source. Even the same organism may be eaten by several organisms of a higher trophic level or an organism may feed upon several different organisms of a lower trophic level. Usually the kind of food changes with the age of the organism and the food availability. Thus, in a given ecosystem various food chains are linked together and intersect each other to form a complex network called food web.

A classification of organisms by trophic levels is one of function and not of species as such. A given species may occupy more than one trophic level. The complexity of food web can vary greatly, and we express this complexity by a measure called the connectance of the food web:

$$\text{Connectance} = \frac{\text{Actual number of interspecific interactions}}{\text{Potential number of interspecific interactions}}$$

Ecological pyramids

In the successive steps of grazing food chain-photosynthetic autotroph, herbivorous heterotroph, carnivores heterotrophs, decay bacteria-the number and mass of the organisms in each step is limited by the amount of energy available. Since some energy is lost as heat, in each transformation the steps become progressively smaller near the top. This relationship is sometimes called "ecological pyramid". The ecological pyramids represent the trophic structure and also trophic function of the ecosystem. In many ecological pyramids, the producer form the base and the successive trophic levels make up the apex.

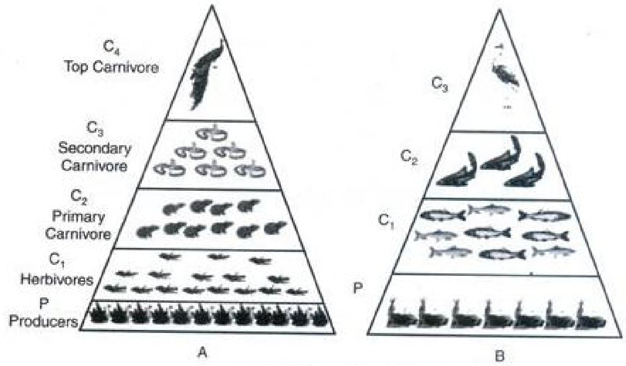
Thus, communities of terrestrial ecosystems and shallow water ecosystems contain gradually sloping ecological pyramids because these producers remain large and characterized by an accumulation of organic matter. This trend, however, does not hold for all ecosystems. In such aquatic ecosystems as lakes and open sea, primary production is concentrated in the microscopic algae.

These algae have a short-cycle, multiply rapidly, accumulate little organic matter and are heavily exploited by herbivorous zooplankton. At any one point in time the standing crop is low. As a result, the pyramid of biomass for these aquatic ecosystems is inverted: the base is much smaller than the structure it supports.

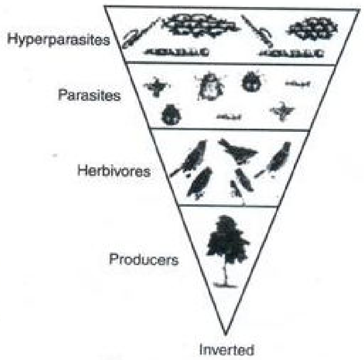
Types of ecological pyramid

1. **Pyramid of number.** Depicts the number of individual organisms at different trophic levels of food chain. This pyramid was advanced by Charles Elton (1927), who pointed out the great difference in the number of the organisms involved in each step of the food chain. The animals at the lower end (base of pyramid) of the chain are the most abundant. Successive links ofcarnivores decrease rapidly in number until there are very few carnivores at the top. The pyramid of number ignores the biomass of organisms and it also does not indicate the energy transferred or the use of energy by the groups involved. The lake ecosystem provides a typical example for pyramid of number.
2. **Pyramid of biomass.** The biomass of the members of the food chain present at any one time forms the pyramid of the biomass. Pyramid of biomass indicates decrease of biomass in each trophic level from base to apex. For example,the total biomass of the producers ingested by herbivores is more than the total biomass of the herbivores in an ecosystem. Likewise, the total biomass of the primary carnivores (secondary consumer) will be less than the herbivores and so on.
3. **Pyramid of energy.** When production is considered in terms of energy the pyramid indicates not only the amount of energy flow level, but more important, the actual role the various organisms play in the transfer of energy. The base upon which the pyramid of energy is constructed is the quantity of organisms produced per unit time, or in other words, the rate at which food material passes through the food chain. Some organisms may have a small biomass, but the total energy they assimilate and pass on, may be considerably greater than that of organisms with a much larger biomass. **Energy pyramids are always slopping** because less energy is transferred from each level than was paid into it. In cases such as in open water communities the producers have less bulk than consumers but the energy they store and pass on must be greater than that of the next level. Otherwise the biomass that producers support could not be greater than that of the

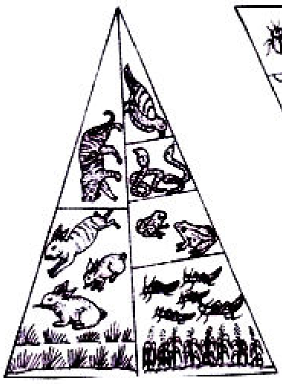
producers themselves. This high energy flow is maintained by a rapid turnover of individual plankton, rather than an increase of total mass.



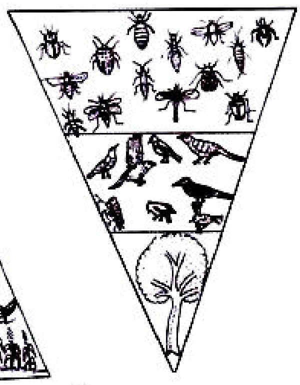
Upright Pyramid of Numbers
(A) Grassland Ecosystem (B) Pond Ecosystem



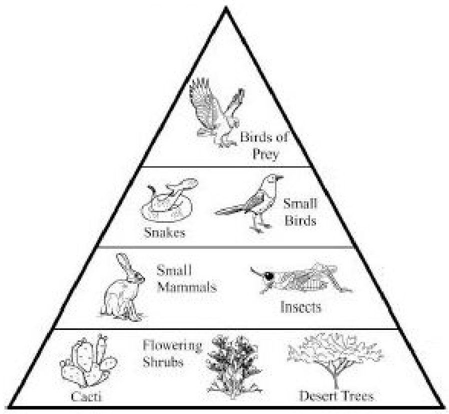
Pyramid of number in Forest Ecosystem



UPRIGHT PYRAMID OF BIOMASS
(GRASSLAND ECOSYSTEM)



INVERTED PYRAMID OF BIOMASS
(AQUATIC ECOSYSTEM)



UPRIGHT PYRAMID OF ENERGY
(DESERT ECOSYSTEM)

Decomposition

The organism who perform the activity of decomposition in an ecosystem are known as decomposers, reducers, saprotrophs (sapro= decompose), osmotrophs (osmo= to pass through a membrane) and scavengers. These include microorganisms such as bacteria, actinomycetes and fungi. They breakdown complex organic compounds of dead or living protoplasm, absorb some of the decomposition or breakdown products and release inorganic nutrients in the environment, making them available again to autotrophs or producers. Some invertebrate animals such as protozoa, oligochaeta such as earthworms, etc., use the dead organic matter for their food, as they have the essential enzymes and hence, can be classified as decomposer organisms.

The disintegrating dead organic matter is also known organic detritus (Latin word deterere means to wear away). By the action of detritivores the disintegrating detritus result into particulate organic matter (POM) and dissolved organic matter (DOM) which play important role in the maintenance of the edaphic environment.

4.6 Structure and functions of some Indian ecosystems

4.6.1. Terrestrial Ecosystems

4.6.1.1. Forest ecosystem

Forests occupy roughly 40 per cent of the land. In India, the forests occupy roughly one-tenth of the total land area. The different components of a forest ecosystem like others, are as follows:

Abiotic component

These are the inorganic as well as organic substances present in the soil and atmosphere. In addition to the minerals present in forests we find the dead organic debris the litter accumulation, chiefly in temperate climate. Moreover, conditions are different due to complex stratification in the plant communities.

Biotic component

The living organisms present in the food chain occur in the following order:

1. Producers

These are mainly trees that show species diversity and much greater degree of stratification especially in tropical moist deciduous forests. The trees are of different kinds depending upon of the forest formation the kind developing in that climate. Besides trees, there are also present shrubs and a ground vegetation. In these forests, dominant members of the flora, the producers such trees as *Tectona grandis, Butea frondosa, Shorea rubusta* and *Lage emia parvifiora*. In temperate coniferous forests, shrubs and ground flora are insignificant. In temperate deciduous forests the dominant trees are species of *Quercus, Acer, Betula, Thuja, Picea* etc., whereas in a temperate coniferous forests, the producer trees are species of *Abies, Picea, Pinus, Cedrus, Juniperus Rhododendron* etc.

2. Consumers.

These are as follows:

(a) Primary consumers: The are the herbivores that include the animals feeding on tree leavesas flies, beetles, leafhoppers, bugs and spiders etc., and larger animals like elephants, nilgai, deer, moles, squirrels, shrews, flying foxes, fruit bats, mongooses etc., grazing on shoots and/or fruits of the producers.

(b) Secondary consumers: These are the carnivores like snakes, birds lizards, fox etc., feeding on the herbivores.

(c) Tertiary consumers: These are the top carnivores like lion, cat,tiger, etc., thatfeeding on carnivores of secondary consumers level.

3. Decomposers

These are wide variety of microoganisms including fungi (species of *Aspergillus, Coprinus, Polyporus, Ganoderma, Fusarium, Alternaria, Trichoderma* ctc.), bacteria(species of *Bacillus, Clostridium, Pseudomonas, Angiococcus* etc.), and *Actinomycetes,* like species of *Streptomyces* etc. Rate of decomposition in tropical and subtropical forests is rapid than that in the more temperate ones.

4.6.1.2. Grassland ecosystem

This is a type of terrestrial ecosystem. Grasslands occupy a comparatively fewer area, roughly 19 per cent of the earth's surface. The various components of land ecosystem are as follows:

Abiotic component

These are the nutrients present in soil and the aerial environment. Thus the elements like C, H,o, N, P, S etc. are supplied by carbon dioxide, water, nitrates, phosphates and sulphates etc., present in air and soil of the area. Morever, in addition to the above, some trace elements arc also present in soil.

Biotic component

These may be categorised as:

1. Producers.

They are mainly grasses, as species *of Dichanthium, Cynodon, Desmodium, Digitaria, Dactyloctenium, Brachiaria, Setaria, Sporobolus* etc. Besides them a few forbs and shrubs also contribute to primary production.

2. Consumers.

These occur in the following sequence:

(a) Primary consumers. The herbivores feeding on grasses are mainly such grazing animals as cows, buffaloes, deers, sheep, rabbit, mouse etc. Besides them, there are also present some insects as *Leptocorisa, Dysdercus, oxyrhachis, Cicincella, Coccinella*, some termites and millipeds etc, that feed on the leaves of grasses.

(b) Secondary consumers. These are the carnivores feeding on herbivores. These include the animals like fox, jackals, snakes, frogs, lizards, birds etc. Sometimes the hawks feed on the secondary consumers, thus occupying tertiary consumers level in the food chain.

(c) Decomposers. The microbes active in the decay of dead organic matter of different forms of higher life are fungi, as species of *Mucor, Aspergillus, Penicillium, Cladosporium, Rhizopus, Fusarium* etc., and some bacteria and actinomycetes. They bring about the minerals back to the soil, thus making them available to the producers.

4.6.2. Aquatic ecosystem

4.6.2.1. Fresh water ecosystem

A pond as a whole serves a good example of a freshwater ecosystem. A pond induced exhibits a self sufficient, self-regulating system. Not only is the pond a place where plants and animals (living organisms) live, but plants and animals make the pond what it is (physico chemical environment). This would bccome clear if you examine a bottle full of pond water or a scoop full of bottom mud, which shall show the living organisms(plants as well as animals and a mixture of inorganic and organic compounds. Some larger forms of life are also present in pond. Thus, whole system becomes much complex indeed. However, we may study the pond as an ecosystem by making its convenient division into some basic components, as shown in Figure. These components are as follows:

Abiotic component

The chief substances are heat, ligh, pH value of water, and the basic inorganic and organic compounds, such as water itself carbon dioxide gas, oxygen gas, calcium, nitrogen, phosphates, amino acids, humic acid etc. Some proportions of nutrients are in solution state but most of them are present as stored in particulate matter as well as in living organisms. The light intensity is measured by a Lux-photometer. Turbidity index of water at different depths is obtained by a Sechhi disc. Rates of are calculated The pHof water and mud is determined by an electric pH meter. Dissolved oxygen content, carbon dioxide content, solute contents including colloidal suspensions, phosphate and nitrogen contents of water, and plant and animal matter are estimated by appropriate methods. Amounts of various organic compounds(carbohydrates, proteins, lipid etc. are also estimated for biomass determination.

Biotic component

The various organisms that constitute the biotic component are as follows

1. **Producers**. These are autotrophic, green plants and some photosynthetic bacteria. The producers fix radiant energy and with the help of minerals derived from the water and mud, they manufacture complex organic substances as carbohydrates, proteins, lipids etc. Producers are of the following types:

   (a) Macrophytes. These are mainly rooted larger plants which include partly or completely submerged, floating and emergent hydrophytes. The common plants are the species of *Trapa, Typha, Eleocharis, Sagittaria, Nymphaea Potamogeton, Chara, Hydrilla, Vallisneria, Utricularia, Marsilea, Nelumbo* etc. Besides thcm some free-floating forms as *Azolla, Salvinia, Wolffia, Eichhornia, Spirodella, Lemna* etc. also occur in the pond.

   (b) Phytoplanktons. These are minute, floating or suspended lower plants. Majority of them are such filamentous algae as *Zygnema, Ulothrix, Spirogyra Cladophora* and *Oedogonium*. Besides them there are also present some. chlorococcales, *Closterium*, *Cosmarium, Eudorina, Pandorina, Pediastrum, Scendesmus, Volvox,* Diatoms, *Anabaena*, some chroococcales, *Gloeotrichia, Microcystis, oscillatoria, Chlamydomonas, Spriulina* etc. and also some flagellates.

   Macrophytes may be sampled by quadrat method in a unit volume of water. Biomass is estimated as weight of standing crop per unit area or volume. Generally, biomass of vegetation decreases from the margin of the pond towards its centre. Energy contents of macrophytes may be estimated by igniting the samples in an Oxygen-Bomb-Calorimeter. The encergy content is generally expressed in terms of Cal/g dry wt or Cal/g ash-free dry wt. The rates of radiant energy fixation during photosynthesis are also determined by appropriate methods. Generally, the energy content of vegetation decreases from margin towards the centre of pond Phytoplanktons are sampled by nets tied to a collection glass bottle. Their biomass is estimated in terms of number per unit volume of water, after sedimentation. It is expressed as average biomass/cubic meter of water.

2. **Consumers**. They are heterotrophs which depend for their nutrition on the organic food manufactured by producers, the green plants. Most of the consumers are herbivores, a few as insects and some large fish are

carnivores feeding on herbivores. Some fish also feed on other carnivores as well. The consumers in a pond are distinguished as follows:

(a) Primary consumers (herbivores). Also known as primary macroconsumers, these are herbivores feeding directly on living plants(producers) or plant remains. These may be large as well as minute in size. The herbivores are further differentiated as:

(i) Benthos. These are(i) the animals associated with living plants (producers) labelled as 'a' in diagram, and (ii) those bottom forms which feed upon the plant remains lying at the bottom of pond. These are known as detritivores. Benthic populations include fish, insect larvae, beetles, mites, molluscs, crustaceans etc. Weight of benthic fauna is estimated in different zones of the pond, and the biomass expressed as g/m2 of water Besides the above said herbivores, some mammals as cows, buffaloes etc. also visit the pond casually and feed on marginal rooted macrophytes. Some birds also regularly visit the pond feeding on some hydrophytes.

(ii) Zooplanktons. These are chiefly the rotifers as *Brachionus, Asplanchna, Lecane* etc., although some protozoans as *Euglena, Coleps, Dileptus etc*., and crustaceans like *Cyclops, Stenocypris* etc. are also present. They feed chiefly phytoplanktons.

(b) Secondary consumers (carnivores). They are the carnivores which feed on the primary consumers(herbivores). These are chiefly insects and fish. Most insects as water beetles feed on zooplanktons.

(c) Tertiary consumers (carnivores). There are some large fish as game fish that feed on the smaller fish, and thus become the tertiary(top) consumers as shown in diagram. In a pond, fish may occupy more than one trophic levels. As shown in Figure, the smaller fish belong to herbivores levels, feeding on phytoplanktons as well as living plant partsand also on plant remains lying at the bottom. Some fish may feed on some zooplanktons, thus occupying the secondary consumers level the carnivores level. Still, it is common to observe the large fish feeding on smaller fish, and thus occupying the tertiary consumers level.

3. **Decomposers**. They are also known as microconsumers since they absorb only a fraction of the decomposed organic matter. They bring about the decomposition of complex dead organic matter of both producers(plants) as well as the macroconsumers(animals) to simple forms. Thus they play an important role in the return of mineral elements again to the medium of the

pond. These include a variety of heterotrophic microbes that are osmotrophs. These are sampled by the use of several isolation methods. They are chiefly bacteria, actinomycetes and fungi. Fungi are isolated by Warcup's method on Martin's medium, bacteria on Thornton's medium, andactinomycetes on Jenson'smedium.Among fungi, species of *Aspergillus, Cephalosporium, Cladosporium, Rhizopus,Pythium, Paecilomyces, choderma Circinella, Fusarium*, *Saprolegnia* etc. are most common decomposers in water and mud of the pond.

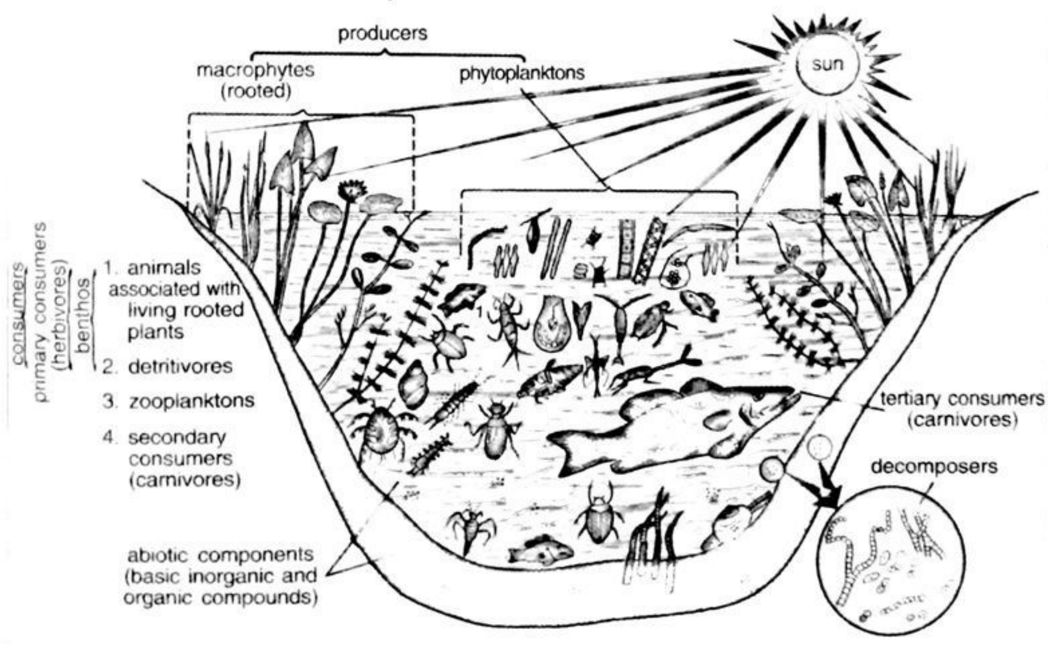


Figure: A pond (freshwater) ecosystem showing its basic structural units

4.6.2.2. Marine ecosystem

Marine ecology emphasizes the totality or pattern or relationships between organisms and the sea environment. The study of the sea in all of its aspects physical, chemical, geological and biological is termed **oceanography.**

Environmental conditions

The chief ecological features of marine environment are:

(1) The sea is big, covering about 70% of the earth's surface.

(2) The sea is deep and continuous, not separated as are land and fresh water. All the oceans are connected. Temperature, salinity and depth are the chief barriers to free movement of marine organisms.

(3) The sea is in continuous circulation due to wind stress set up by air temperature differences between poles and equator.

(4) The sea is dominated by waves of many kinds and tides produced by the pull of moon and sun.

(5) The scan is salty, with an average salinity of35 parts of salt(weight basis) per 1000 parts of water, or 3.5 per cent, that is usually written as 35% ie. parts per 1000 (cf. salinity of fresh water that is less than 0.5%). The chief salts are chlorides, sulphates, bicarbonates, carbonates and bromides of sodium, magnesium, calcium and potassium, of which sodium chloride is present in maximum amount.

(6) Dissolved nutrients are in a low concentration that is an important limiting factor in determining size of marine populations.

Zonation in the sea: As in ponds and lakes, seas also exhibit a distinct zonation. The various zones of sea are shown in Figure. Generally, there is a continental shelf extending for a distance offshore, beyond which the bottom drops off steeply as the continental slope then levels offsomewhat(the continental rise) before dropping down to a deeper, but more level, plain.The shallow-water zone on the continental shelf is the **neritic(near shore) zone**. The zone between high and low tides(also called the **littoral zone**) is known as the **intertidal zone**. The region of the open sea beyond the continental shelf is called **oceanic region**, which comprises the region of the continental slope and rise the **bathyal zone**; area of the ocean deeps **abyssal region**; and light compensation zone separating an upper thin **euphotic zone** from a vastly thicker **aphotic zone**. Within these primary zones(based chiefly on physical factors), there may occur distinct secondary zoncs, horizontal as well as vertical, insuch waters. Thus communities in each of the primary zones, excepting the euphotic, have two distinct vertical components, the **benthic** (bottom), and the **pelagic.**

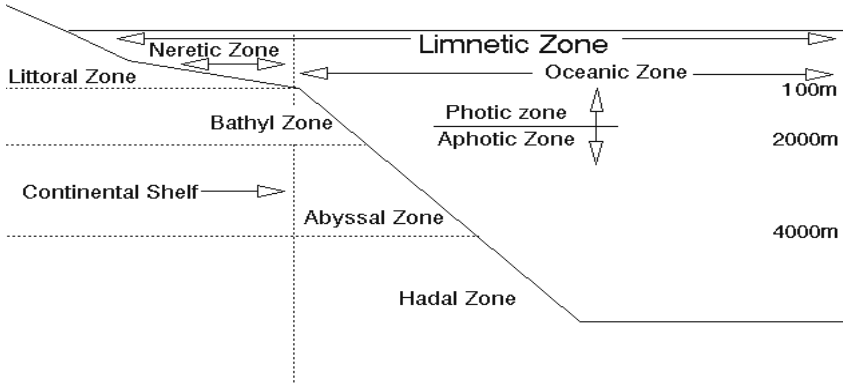


Figure – A sea (marine) ecosystem showing its basic structural units

The communties

The organisms of marine environments show great diversity in their form and it becomes difficult to list dominants' as is possible in fresh waters. Coelenterates, sponges, echinoderms, etc. that are absent or poorly represented in freshwater are very important in marine waters. Bacteria, algae, crustaceans, and fish play a dominant role in both, fresh as well as marine waters, with diatoms, green flagellates, and copepods being equally important to both. Variety of algae(brown and red), crustaceans, molluscs, and fish is greater in marine waters. Seed plants are of little value in sea, excepting for *Zostera*, the eel grass. Thus production is mainly by algae. Insects are generally absent, and the crustaceans constitute the so-called 'insects of the sea'.

The producers in the continental shelf region are chiefly the phytoplanktonic diatoms and dinoflagellates. Near seashore large multicellular attached algae or **seaweeds** are also important that form extensive forests or **Kelp beds** below the tide mark. Green algae, brown algae, and red algae are important producers, of which the litter two are more common.These algae show a depth distribution roughly in the order named(with red algae deepest). Neritic phytoplankton at least in temperate regions undergoes a seasonal density cycle similar to that in eutrophic lakes.

The consumers are,

1. **Zooplanktons.** These are of various types. Those which remain for their entire life cycle as planktons are called **haloplankton**, as copepods, larger crustaceans (kril),euphausids, protozoans, 'wing-footed' molluscs, tiny jellyfish, ctenophores, pelagic tunicates (salps), and free-floating polychaete worms etc. Some of the zooplanktons are called **meroplankton** as most of the benthos, and muchof the nekton (fish) in larval stages join the plankton as assemblage for varying periods.
2. **Benthos.** These are in large numbers and are sessile orrelativelyinactive animals in the inshore region. They are distinct in supratidal, intertidal and subtidal zones. These include a variety of crabs, amphipods, tiger, beetles and other insects, periwinkles, isopods, ghost shrimps, barnacles, oysters, mussels, dollars, clams, shells, corals, sea anemone etc.
3. **Nekton and neuston.** These are swimming animals which include fish, turtles, such mammals as whales, seals, etc., and the marine birds.

Moreover, some other animals that feed on planktons are also found, which include herring, menhaden, sardine etc.

4. **Bacteria.** These are present in less amount being mainly as sediments. Fungi and yeasts are not very important in such habitat.

In the oceanic region, communities are chiefly of pelagic and benthic type.

4.6.2.3. Estuarine ecosystem

An estuary is a semi-enclosed coastal body of water which has a free in present connection with the open sea, thus strongly affected by tidal action, and within which sea water is mixed with fresh water from land drainage. Examples of The estuaries are river mouths, coastal bays, tidal marshes, and water bodies behind barrier beaches. Thus, estuaries may be considered as transitional zones or ecotones between the freshwater and marine habitats. Estuaries are variously classifiedon the basis of their geomorphology, water relative circulation and stratification and systems energetics. Based on geomorphology, the van estuaries are (i) drowned river valleys, (ii) ford-type estuaries, (ii) bar-built estuaries, (iv) estuaries produced by tectonic processes, (v) river delta estuaries etc.

On the basis of water circulation and stratification, estuaries are classified as(i) highly stratified or salt-wedge estuaries, (ii) partially mixed or moderately stratified estuaries, (iii) completely mixed or vertically homogeneous estuaries and(iv) hypersaline estuaries. Based on the ecosystem energetics, as done by Odum et al(1969), estuaries are classified as (i) physically stressed systems of differ wide latitudinal range, (ii) natural arctic ecosystems with ice stress, (ii) natural temperate coastal ecosystems with seasonal programming, (iv) natural tropical coastal ecosystems of high diversity, and(v) emerging new systems associated with man.

Communities of estuaries are a mixture of endemic species and those which come in from sea. An estuary consists of several basic subsystems linked together by the ebb and flow of water that is driven by the hydrological cycle and the tidal cycle.

The chief subsystems are:

a) Shallow water production zones

Here rate of primary production exceeds the rate of community respirations. The producers are reefs, banks, seaweed or sea grass beds, algal mats and salt marshes. This system exports energy and nutrients to deeper waters of the estuary and adjacent coastal shelf. Estuaries are equivalent to tropical rain forest and coral reefs as natural productive ecosystems. Indeed estuaries are more productive than either the sea on one side or the freshwater drainage on the other. Estuaries are said to be the nutrient traps. Being rich in diverse types of producers these remain 'programmed' for virtually year around photosynthesis and derive benefit from tidal action in creating a subsidized fluctuating water-level ecosystem. They have all the three types of producers, the macrophytes(sea-weeds, sea grass and marsh benthic and phytoplanktons. The important macrophytes *Spartina, Zostera* and *Thalassia*. Benthic algae grow on macrophytes and sessile animals as well as on rocks, sand and mud. Moreover, estuaries possess distinct blooms such as red tides of large blooms of red pigmented dinoflagelates, such as species of *Gonyaulax* and *Gymnodinium*.

b) Sedimentary subsystems

These are present in the deeper channels, sounds and lagoons in which respiration exceeds production and in which particulate and dissolved organic matter from the production zone is used. Here nutrients are regenerated, recycled, stored and vitamins and growth regulators are manufactured. The consumers are often versatile in their feeding habits. They are more or less similar to those present in marine environment though well developed in estuaries.

c) Plankton and nekton

They move freely between the two abovesaid fixed subsystems. They keep on producing, converting and transporting nutrients and energy while responding to diurnal, tidal and seasonal periodicities. Generally, holoplankton comprises relatively few species, while the meroplanktons tend to be more diverse, reflecting the variety of benthic habitats.

4.7 Self learning exercise

Part-A (Very short answer types)

1. Define succession.
2. Write the basic types of succession.
3. What do you mean by pioneer species?
4. Define ecosystem.

5. What do you mean by food Chain and food Web?
6. What are ecosystem energetics?

Part-B (short answer types)

1. Write short notes. (i) Secondary succession (ii) Climax (iii) Heterotrophic succession
2. Differentiate between primary and secondary succession.
3. Explain the following:
   (i) Ecological pyramid
   (ii) Productivity
   (iii) Primary productivity and secondary productivity
4. Give comparative account of grazing and detritus food chains.
5. What are the roles of decomposers in an ecosystem?

Part-C (Long answer types)

1. Describe the causes, trends and basic types of succession.
2. Give an account of the sequential stages of a typical hydrosere.
3. Describe the energy flow in a typical ecosystem.
4. Describe the biotic and abiotic component of any aquatic or terrestrial ecosystem.
5. What are the factors that affect net primary production in plants?

4.8 References

- ***Ecology and environment***: P. D. Sharma; Rastogi publications.
- ***Cell biology, Genetics, Molecular Biology, Evolution and Ecology***: P.S. Verma and V.K. Agarwal. S. Chand publications.
- ***http/wekipedia.com***

Unit - 5

Biography and Applied Ecology

Structure of the Unit

5.0 Objectives

After going through this unit you will be able to understand

- Which are the major biomes of the earth.

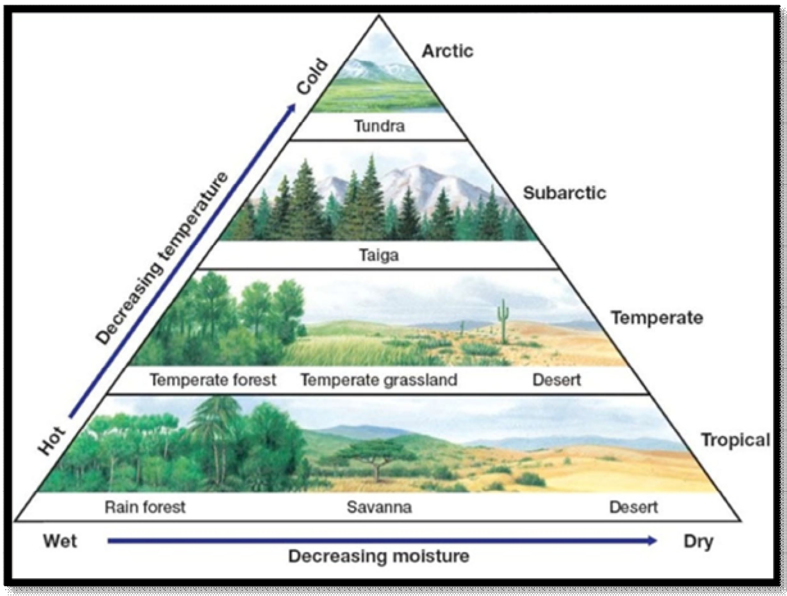
- What is Island Biogeography and how does it help us in understanding Evolution
- Ten bio-geographic regions of India and specific flora and fauna of each region
- Various types of pollution, pollution causing agents and mitigation of various types of pollutions
- Global Environment changes with special reference to El Nino and La Nina
- Natural disasters, particularly Tsunami and Earthquakes and their impacts on Humans
- Values and threats to the biodiversity, its conservation, Biological Diversity Act factors affecting it
- Biodiversity hotspots of India
- Kaziranga National Park. A UNESCO world heritage site

5.2 Major Terrestrial Biomes

Biomes are very large areas on earth's surface with flora and fauna adapted for that particular environment. According to Campbell, **Biomes** can be defined as "the world's major communities, classified according to the predominant vegetation and characterized by adaptations of organisms to that particular environment". Biomes can be classified into following categories:

Desert **Aquatic** **Forests** **Grassland** **Tundra**

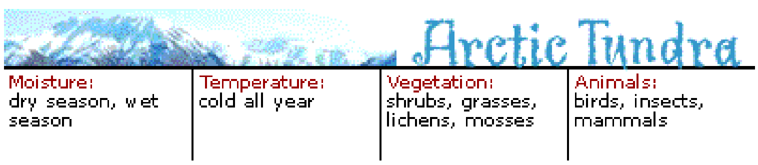
The importance of biomes cannot be underestimated. Biomes have changed and moved many times during the history of life on Earth. More recently, human activities have drastically altered these communities. Thus, conservation and preservation of biomes is a major concern to all. Moisture and temperature are important factors which influence the biome greatly. Biomes can be classified into the categories as shown in the following figure.



Important terrestrial biomes can be classified into the following six categories:

5.1.1 Arctic Tundra:

Arctic tundra is found across northern Alaska, Canada, and Siberia. This biome has long cold winters and short cool summers. The Arctic tundra has low precipitation (less than 10 inches per year) and dry winds. These conditions give Arctic tundra a desert-like climate. One unique characteristic of the Arctic tundra is permafrost – ground that is permanently frozen. Because the permafrost has no cracks or pores, nothing can penetrate it. The surface layer above the permafrost softens each summer. This layer is called the active layer. Thickness of the active layer depends on its location in the tundra. The northerly located areas have thinner active layers.



During the summer Arctic tundra is characterized by lots of surface water. The snow melts during this period and the water percolates through the active layer but is unable to penetrate the permafrost. Since the water has nowhere to go, the active layer becomes saturated and pools of water are formed on the surface. Another characteristic of the Arctic tundra is the limited amount of sunlight it receives due to the position of the Sun in the sky. Depending on the latitude, the

Sun can remain below the horizon for up to 2 months, leaving the Arctic tundra in darkness. Although the sun remains in the sky 24 hours a day during the summer, it stays close to the horizon and provides only low intensity sunlight.

Animals: Not many kinds of animals live year-round in the Arctic tundra. Most birds and mammals only use the tundra as a summer home. Mammals that do live year-round in the tundra include the muskox, Arctic wolf, and brown bear. Animals need to find ways to stay warm and to provide nourishment for themselves in order to survive the long and cold winter months. Migration and hibernation are examples of behavioral adaptations used by animals in the Arctic tundra. The fact that many animals do not live year-round in the tundra means they leave or migrate for a length of time to warmer climates. Hibernation is a combination of behavioral and physical adaptations. For example, during the summer the brown bear's behavior is to eat just about anything it can find; then it hibernates, or sleeps, during the winter. The bear's physical adaptation allows the food eaten during the summer to be stored as a layer of fat underneath its skin. The layer of fat insulates the bear from the cold. While in hibernation the fat is slowly converted into energy that maintains life.

A physical adaptation used by the Musk Ox is the growth of two layers of fur – one short and the other long. Air is trapped in the short layer of fur and is warmed by body heat. The warmed air, trapped close to the body, acts as insulation from the cold. The layer of long fur protects the Musk Ox from the wind and water. In addition to thick layers of fur, the Musk Ox relies on another physical adaptation to help it survive. The hooves of the Musk Ox are large and hard. During the winter months, this adaptation allows the Musk Ox to break the ice and drink the water underneath.

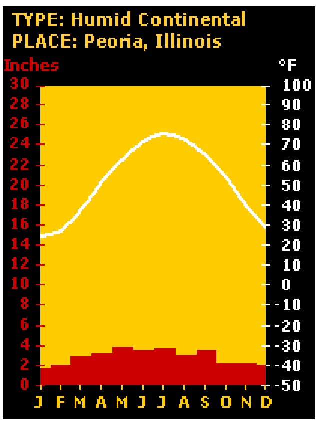
Plants: "Tundra" is a Finnish words which means "treeless". Plants need warmth and sunlight to grow and reproduce. In the Arctic tundra, warmth and sunlight are in short supply, even in the summer. The ground is frequently covered with snow until June, and the Sun is always low in the sky. The plants with shallow root systems grow in the Arctic tundra because the permafrost prevents plants from sending their roots down past the active layer of soil. The active layer of soil is free from ice for only 50 to 90 days.

Arctic plants have a very short growing season. However, in spite of the severe conditions and the short growing season, there are approximately 1,700 kinds of plants that live in the Arctic tundra. Some of the plants that live in the Arctic tundra include mosses, lichens, low-growing shrubs, and grasses--but no trees.

Growing close together and low to the ground are some of the adaptations that plants use to survive. This growing pattern helps the plant resist the effects of cold temperatures and reduce the damage caused by the impact of tiny particles of ice and snow that are driven by the dry winds. Plants also have adapted to the Arctic tundra by developing the ability to grow under a layer of snow, to carry out photosynthesis in extremely cold temperatures, and for flowering plants, to produce flowers quickly once summer begins. A small leaf structure is another physical adaptation that helps in survival of plants. Plants lose water through their leaf surface. By having small leaves the plant is more able to retain the moisture it has stored.

5.1.2 Deciduous Forest:

The mid-latitude deciduous forest biome is located between the polar regions and the tropics. Because of its location, air masses from both the cold polar region and the warm tropical region contribute to the changes of climate in this biome. Mid-latitude deciduous forests have both a warm and a cold season. Precipitation ranges from 30 to 60 inches and is evenly distributed throughout the year. Much of the human population lives in this biome. Although evergreens are found in this biome, this biome is characterized by an abundance of deciduous trees. "Deciduous" means to fall off, or shed. Just as the name indicates, these deciduous trees shed their leaves in each fall season. The leaves lying on the forest surface decay and as the leaves decompose, the nutrients contained in the leaves are absorbed by the soil. For this reason, the soil of this biome is very fertile. Because this biome has fertile soil and a long growing season, many deciduous forests have been converted into agricultural regions.



Animals: A wide variety of mammals, birds, insects, and reptiles can be found in a deciduous forest biome. Mammals that are commonly found in a deciduous forest include bears, raccoons, squirrels, skunks, wood mice, and deer. While bobcats, mountain lions, timber-wolves, and coyotes are natural residents of these forests, they have nearly been eliminated by humans because of their threat to human life. Other animals that were native to this biome, such as elk and bison, have been hunted to near extinction. Migration and hibernation are two adaptations used by the animals in this biome. While a wide variety of birds migrate, many of the mammals hibernate during the cold winter months when food is in short supply. Another behavioral adaptation some animals have adopted is food storage. The nuts and seeds that are plentiful during the summer are gathered by squirrels, chipmunks, and some jays, and are stored in the hollows of trees for use during the winter months. Cold temperatures help prevent the decomposition of the nuts and seeds.

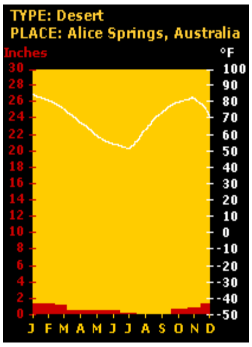
Plants: Trees of this biome include both broadleaf, deciduous trees, such as maple, oak, hickory, and beech, and evergreens, such as hemlock, spruce, and fir. A deciduous forest typically has three to four, and sometimes five, layers of plant growth. Tall deciduous trees make up the top layer of plant growth, and they create a moderately dense forest canopy. Although the canopy is moderately dense, it allows sunlight to reach the forest floor. This sunlight allows plants in the other layers to grow. The second layer of plant growth includes saplings and species of trees that are naturally shorter in stature. A third layer/understory includes shrubs. Forest herbs, such as wildflowers and berries, make up a fourth layer. During the spring, before the deciduous trees leaf out, these herbs bloom and grow quickly in order to take advantage of the sunlight. A fifth layer would include mosses and lichens that grow on tree trunks. Cooler temperatures and limited sunlight are two climatic conditions that tell the tree to begin adapting. In the Fall, when these conditions occur, the tree cuts off the supply of water to the leaves and seals off the area between the leaf stem and the tree trunk. With limited sunlight and water, the leaf is unable to continue producing chlorophyll, and as the chlorophyll decreases the leaves change color. The beautiful display of brilliant red, yellow, and gold leaves, associated with deciduous forests in the fall, is a result of this process. Most deciduous trees shed their leaves, once the leaves are brown and dry.

5.1.3 Desert

The defining characteristic of desert are that it is dry, with little or no precipitation, deep under-ground water, high wind velocity and high day temperature. Depending on its geographical location, the annual precipitation in a desert varies from half an inch to as much as 15 inches. Rainfall is usually very low and erratic. At times in the Atacama Desert in Chile, years have passed with no measurable rainfall at all. Deserts can be either hot such as the

Australian Desert or cold such as the Gobi Desert. As with all biomes, the desert climate is determined by geographic conditions. Geographic conditions such as location, high atmospheric pressure, and proximity of mountain ranges determine just what type of desert it is.

Because all deserts are dry, they have large daily temperature variations. Temperatures are high during the day because there is very little moisture in the air to block the Sun's rays from reaching Earth. Once the Sun goes down, the heat absorbed during the day quickly escapes back into space. High daytime temperatures and low nighttime temperatures make survival in the desert very difficult.



Animals: At first glance, deserts may appear to be without animal life. However, deserts are home to many reptiles, insects, birds, and small mammals. The kangaroo mice of North America and the bilby and red kangaroo of Australia are just a few examples of small mammals that live in the desert. Most large animals have not adapted to desert life. Their size prevents them from finding shelter from the Sun's heat and they are not able to store water for future use. Animals that do survive in the desert have developed a number of adaptations. The most universal behavioral adaptation used by small mammals, reptiles, and insects to deal with high temperatures is staying in the shade of plants or rocks, thus avoiding the direct rays of the Sun. These animals also seek shelter by burrowing into the ground, just a few feet underground can decrease the temperature by several degrees. Another behavioral adaptation used by desert animals is to remain inactive during the hot daylight hours. They hunt at night when temperatures are cool and when there is less risk of losing precious body water. Some animals get all of the water they need from the insects, bulbs, and seeds they eat. They will not drink water even when it is available. Some animals have developed salt glands, a physical adaptation that allows the secretion of salt without the loss of water. The absence of sweat glands, and the concentration of urine are other physical adaptations made by desert animals. Because fat intensifies heat, a unique physical adaptation of some desert animals is the storage of fat in humps or tails, rather than throughout the entire body.

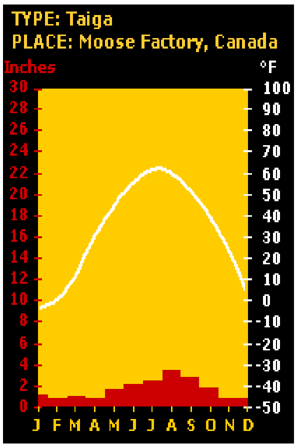
Plants: Short grasses, sagebrush, creosote bushes, and cacti are just a few of the plants that can be found in the desert. Plant abundance and variety are determined by the geographic location of the desert. Although short grasses can be found in nearly all desert locations, the saguaro cactus is unique to the Sonoran Desert, and the spiniflex is associated with the Australian Desert. Because of the dry climate, plants have developed a number of different methods of capturing water. Some plants have developed long (20-30 foot) taproots that go deep into the ground and tap into groundwater sources. Other plants have developed extensive horizontal root systems. These horizontal root systems lie just below the surface and extend far beyond the plant canopy. When it rains the numerous tiny roots capture the water. Another common physical adaptation is the ability of desert plants to store water in their roots, stems, leaves, or fruit. Plants that store water in this way are referred to as succulents, and they include cacti.

Desert plants retain moisture by limiting water loss through their leaf surface. Many plants accomplish this by adapting the size, sheen, or texture of their leaves. Small leaves or spines limit the amount of surface area exposed to the drying heat. Glossy leaves reflect the Sun's radiant heat reducing leaf temperatures and evaporation rates. Waxy leaves prevent moisture from escaping. Water escapes from leaves through the stomata, or leaf pores. A behavioral adaptation used by some plants is to only open leaf pores during the night when air temperature is cool and evaporation rate is low.

5.1.4 Taiga

The taiga biome is found in the northern hemisphere close to the polar region. This cold biome stretches across the northern portions of North America, Europe, and Asia. Large population centers, such as Moscow and Toronto, can be found in the southern portion of this biome, but the northern portion is relatively unpopulated. Within this biome, there is a wide range of temperatures between winter and summer seasons. Winters are long and cold, and the summers are short and cool. Precipitation is moderately high throughout the year with snow occurring during the winter months.

Most of the taiga in North America was once covered with glaciers that have receded, leaving hollows and depressions in the topography. Since there is moderately high precipitation, these depressions are frequently filled with water, creating bogs and lakes. The soil found in the taiga is low in nutrients and highly acidic. It also is rocky and covered with undecayed leaf litter. Patches of permafrost can also be found in areas of the taiga.



Animals: The cold climate of the taiga prevents many animals from living there year-round. Some of the large animals found in the taiga include moose, deer, and bears. Examples of smaller animals that live in the taiga are bobcats, squirrels, chipmunks, ermine, and moles. The taiga is home to many insects and birds such as the bald eagle, chickadee, woodpeckers, and warblers. The bogs and ponds, found throughout the taiga during the summer, provide a wonderful breeding place for a wide variety of insects. Many migratory birds come to the taiga to nest and feed on the huge insect population.

Most animals migrate to warmer climates once the cold weather begins. Some animals have adapted to life in the taiga by hibernating when temperatures drop. Other animals have adapted to the extreme cold temperatures by producing a layer of insulating feathers or fur to protect them from the cold. In some instances, the adaptation of a seasonal change in color of feathers or fur protects the animal from its predators. Ermine, a small mammal, is a good example of this adaptation. Its dark brown summer coat changes to white in the winter. This adaptation helps the ermine blend into its surroundings and makes it more difficult for the ermine's predators to spot them.

Plants: Because the climate of the taiga is very cold, there is not a large variety of plant life. Common types of trees found in the taiga are the conifer trees that have cones. Four kinds of conifers are common in the taiga. Three of the common conifers are evergreens; spruce, fir, and pine. The fourth common conifer is the tamarack, or larch, a deciduous tree. Under certain conditions, broadleaf trees, such as birch and aspen, are able to survive the harsh climate of the taiga. Evergreens use a wide variety of physical adaptations. Some of these adaptations include their shape, leaf type, root system, and color. They are always or ever green. Because they don't drop their leaves when temperatures cool, they don't have to re-grow leaves in the spring. Growing new leaves takes a lot of energy. Plants get their energy from the soil and from the Sun. Soil is a source of nutrients. Sunlight is necessary for photosynthesis to take place in the plant. The taiga soil doesn't contain many nutrients, and the Sun usually remains low in the sky. These two factors limit the amount of energy available to the tree. By keeping their leaves, the evergreens are able to use that limited energy for structural growth rather than producing leaves.

Although the taiga has moderately high precipitation, the ground freezes during the winter months and plant roots are unable to get water. The adaptation from broadleaf to narrow needle-like structures limits water loss through transpiration. Evergreen needles do not contain very much sap. This limits the risk of needle damage from freezing temperatures. The needles do, however, contain a chemical that repels animals, which would eat the leaves. The dark green color of the needles absorbs the sunlight, and since the needles are always present, once temperature start to get warm, photosynthesis quickly begins. The conical shape of the evergreens allows the snow to slide off the branches rather than pile up. If the snow can't pile up on the branches, there is less risk of broken branches due to the weight of the snow.

5.1.5 Tropical Rainforest:

The tropical rainforest is a hot, moist biome found near Earth's equator. The world's largest tropical rainforests are in South America, Africa, and Southeast Asia. Tropical rainforests receive from 60 to 160 inches of precipitation that is fairly evenly distributed throughout the year. The combination of constant warmth and abundant moisture makes the tropical rainforest a suitable environment for many plants and animals. Tropical rainforests contain the greatest biodiversity in the world. Over 15 million species of plants and animals live within this biome. The hot and humid conditions make tropical rainforests an ideal environment for bacteria and other microorganisms as well. Because these organisms remain active throughout the year, they quickly decompose matter on the forest floor.

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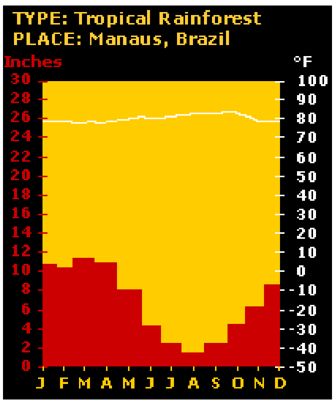
The hot and humid conditions make tropical rainforests an ideal environment for bacteria and other microorganisms. Because these organisms remain active throughout the year, they quickly decompose matter on the forest floor. In other biomes, such as the deciduous forest, the decomposition of leaf litter adds nutrients to the soil. But in the tropical rainforest, plants grow so fast that they rapidly consume the nutrients from the decomposed leaf litter. As a result, most of the nutrients are contained in the trees and other plants rather than in the soil.

Animals: Tropical rainforests support a greater number and variety of animals than any other biome. One of the reasons for this great variety of animals is the constant warmth. Tropical rainforests also provide a nearly constant supply of water and a wide variety of food for the animals. Small animals, including monkeys, birds, snakes, rodents, frogs, and lizards are common in the tropical rainforest. Many of these animals and a large number of insects never set foot on the ground. The animals use the tall trees and understory for shelter, hiding places from their predators, and a source of food.

Because there are so many animals competing for food, many animals have adapted by learning to eat a particular food eaten by no other animal. The bill also is used to cut the fruit from the tree. The lemurs use a behavioral adaptation and camouflage to survive in the rainforest. It moves very slowly and spends most of its time hanging upside down from trees.



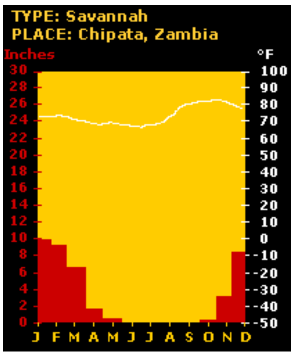
Plants: Although tropical rainforests receive 12 hours of sunlight daily, less than 2% of that sunlight ever reaches the ground. The tropical rainforest has dense vegetation, often forming three different layers – the canopy, the understory, and the ground layer. The canopy created by the tall trees (100-120 feet) and the understory, prevents sunlight from reaching the ground. The soil is, therefore, always shaded, and very little vegetation is able to survive at ground level.

Vegetation can become dense at ground level near riverbanks and on hillsides. Hillsides have more plant growth because the angle of the growing surface allows sunlight to reach lower layers of the forest. Riverbeds break up the forest canopy so that smaller plants can get the needed sunlight. Plant survival in a tropical rainforest depends on the plant's ability to tolerate constant shade or to adapt strategies to reach sunlight. Fungus is a good example of a plant that flourishes in warm, dark places created by the forest canopy and understory.

5.1.6 Tropical Savannah:

The tropical savanna is a biome characterized by tall grasses and occasional trees. Large regions of tropical savanna extend through the nations of Botswana, Namibia and Kenya in Africa, southern Brazil, India, and Australia. Savannas exist in areas where there is a 6 to 8 month wet summer season and a dry winter season. Annual rainfall in savannas varies depending on the geographic location. Some savannas get as little as 10 inches of rain annually while others can get as much as 50 inches. The dry season is marked by months of drought and fire which are essential to the maintenance of savannas. Without the period of drought and fire, some scientists believe that tropical savannas would eventually change into tropical forests.

Savannas can result from either climate, soil conditions, animal behavior, or agricultural practices, which limit the occurrence of trees. Humans create savannas by burning the grasslands and felling the trees in order to plant crops. Large animals such as elephants can turn a forest into a savanna by stripping the bark from the trees, knocking over trees, and trampling on tree seedlings.



Animals: The species of animals in a savanna depends upon the geographic location of the biome. The African savannah, the savannah with which most people are familiar, is home to a wide variety of animals. A short list of some of those animals includes wildebeest, warthogs, elephants, zebras, rhinos, gazelles, hyenas, cheetahs, lions, leopards, ostrich, mousebirds, starlings, and weavers. During the rainy season, birds, insects, and both large and small mammals thrive in the savannah, but the rainy season only lasts 6 to 8 months. During the dry season, surface water from the rain is quickly absorbed into the ground because the soil is extremely porous. Competition for water during the dry season is intense. Consequently, most birds and many of the large mammals migrate during the dry season in search of water. Because drought conditions are sometimes localized, the migration may be just to another area within the savannah. When drought conditions exist for a long time and over a wide area, the animals may migrate to another biome until the rainy season begins again.

Although elephants do migrate, they have a physical adaptation that allows them to access water that is not available to other animals. Baobab trees store water in their large trunks. The elephant's physical strength and anatomy allow it to tear open the trunk of the baobab tree and to suck the water from it. An adaptation used by small burrowing animals is to remain dormant during times of drought – much like bears do during the winter in other biomes. During the dry season, lightning frequently ignites the brown, dry grasses that cover the savannah. Many of the animals have adapted to live with the fires. The ability to fly or to run fast enables most birds and large mammals to escape the flames. Some birds, such as the Fork-tailed Drongos, actually are attracted to the active fires. These birds feast on fleeing or flame-roasted insects. Although small burrowing animals may not be able to outrun the flames, they frequently survive the fire by digging beneath the soil and remaining there until the flames pass by them.

Plants: Grasses are the dominant plant life in the savanna. A wide variety of grasses grow in savannas, but different varieties are found in different savannas. Some grasses grow 6 to 9 feet tall. Trees growing alone or in small clusters are also part of the savanna biome. In fact, without the trees, the savanna biome would be considered a prairie. The variety of trees in a particular savanna is dependent upon the geographic location of the savanna. The acacia and baobab trees are common in African savannas.

In order for the grasses to survive the dry season and the periodic fires, they have developed an adaptation that allows them to grow quickly when there is adequate water. Then when water becomes scarce, the grasses turn brown to limit water loss. They store necessary moisture and nutrients in their roots while they await the return of the rainy season. With food and water reserves stored below ground, the grasses are able to survive the effects of fire as well. In fact, fire stimulates new growth and replenishes the soil with nutrients. The baobab tree has adapted to the savanna biome by only producing leaves during the wet season. When leaves do grow, they are in tiny finger-like clusters. The small size of the leaves helps limit water loss. Another adaptation that enables the baobab tree to survive the long months of drought is its ability to store water in its large trunk. The acacia tree can survive drought conditions because it has developed long tap roots that can reach deep, ground water sources. It is also fire resistant. The acacia tree has developed very useful physical and behavioral adaptations to discourage animals from eating its leaves. It developed long, sharp thorns and a symbiotic relationship with stinging ants. The ants live in acacia thorns they have hollowed out, and they feed on the nectar produced by the tree. When an animal takes a bite of leaves (and thorns), it also gets a mouthful of angry, stinging ants. The ants defend their homes from other insects as well, thus protecting the acacia tree. Giraffes graze on the tops of the acacia, which results in the dome-shaped top characteristic of acacia trees. A behavioral adaptation aimed at preventing giraffe grazing is a chemical defense system that is triggered when the giraffe begins to munch on the leaves. First, a poisonous alkaloid that tastes nasty is pumped into the leaves. The giraffe only gets a couple of mouthfuls of leaves before the remaining leaves become inedible. Then, the tree warns other acacia trees in the area by emitting a chemical into the air. The other acacia trees respond by pumping alkaloid into their leaves.

5.2 Island Biogeography

Two ecologists, Robert H. MacArthur and E. O. Wilson, coined the term *island biogeography* in their theory in 1960s, which attempted to predict the number of species that would exist on a newly created island. **Insular biogeography** is a field within biogeography that examines the factors that affect the species richness of isolated natural communities. The theory was originally developed as **island biogeography** to explain species richness of actual islands, principally oceanic. Now the term is used in reference to any ecosystem that is isolated due to being surrounded by unlike ecosystems, *e.g.* mountain peaks, oases, fragmented forest, and even natural habitats isolated by human land development.

5.2.1 Definition: An insular environment or "island" is any area of habitat suitable for a specific ecosystem, surrounded by an expanse of unsuitable habitat. While this may be a traditional island – a mass of land surrounded by water – the term is now also widely applied to many nontraditional "islands", such as the peaks of mountains, isolated springs or lakes surrounded by desert, and non-continuous woodlands *etc*. The concept is even applied to natural habitats surrounded by human-altered landscapes, such as large grasslands surrounded by highways or housing tracts, and national parks. What is an insular for one organism may not be so for others, some organisms located on mountain tops may also be found in the valleys, while others may be restricted to the peaks only.

5.2.2 Theory: The theory of insular biogeography proposes that the number of species found in an undisturbed insular environment ("island") is determined by immigration and extinction. The isolated populations may follow different evolutionary routes, as shown by Darwin's observations on finches in the Galapagos Islands. Immigration and emigration are affected by the distance of an island from a source of colonists (distance effect). Usually this source is the mainland, but it can also be other islands. Islands that are more isolated are less likely to receive immigrants than islands that are less isolated. Once a species manages to colonize an island, the rate of extinction is affected by island size; this is the **"species-area curve"**. Larger islands contain larger habitat areas and opportunities for more varieties of habitats. Larger habitat size reduces the probability of extinction due to chance events. Habitat heterogeneity increases the number of species that will be successful after immigration. Over time, the forces of extinction and immigration result in an equilibrium level of species richness.

5.2.3 Modifications: In addition to having an effect on immigration rates, isolation can also affect extinction rates. Populations on islands that are less isolated are less likely to go extinct because individuals from the source population and other islands can immigrate and stops the population from being extinct; this is known as the **"rescue effect"**. In addition to having an effect on extinction, island size can also affect immigration rates. Species may actively target larger islands because of greater resources and available niches; or, larger islands may accumulate more species by chance just because they are larger. This is known as the **"target effect"**.

5.2.4 Influencing factors: Total numbers of species on small and large islands are influenced by the following factors:

- Degree of isolation (distance to nearest neighbor, and mainland)
- Length of isolation (time)

- Size of island (larger area usually facilitates greater diversity)
- The habitat suitability which includes:
- Climate (tropical versus arctic, humid versus arid, *etc*.
- Initial plant and animal composition if previously attached to a larger land mass (*e.g.* marsupials, primates)
- The current species composition
- Location relative to ocean currents (influences nutrient, fish, bird, and seed flow patterns)
- The impacts of chance arrivals
- Human activity

5.2.5 Historical record: The theory can be studied through the fossils, which provide a record of life on Earth. 300 million years ago, Europe and North America lay on the equator and were covered by steamy tropical rainforests. Climate change devastated these tropical rainforests during the Carboniferous Period and as the climate grew drier, rainforests fragmented. Shrunken islands of forest were uninhabitable for amphibians but were well suited to reptiles. As a result the reptiles became more diverse and even varied their diet in the rapidly changing environment. This Carboniferous rainforest collapse event triggered an evolutionary burst among reptiles.

5.2.6 Applications of Island biogeography in conservation biology: Within a few years of the publishing of the theory, its potential application to the field of conservation biology had been realized. The reserves and national parks formed islands inside human-altered landscapes (habitat fragmentation), and that these reserves could lose species as they 'relax towards equilibrium'. This is particularly true when conserving larger species which tend to have larger home ranges. It has been shown that there is a strong correlation between the size of a protected National Park and the number of species of mammals. This led to the debate about single large or several small (SLOSS) protected areas for conservation. It is now the general assumption that one large reserve could hold more species than several smaller reserves, and that larger reserves should be the norm in reserve design. Howsoever, some scientists are of the opinion that habitat diversity was as or more important than size in determining the number of species protected.

Island biogeography theory also led to the development of wildlife corridors as a conservation tool to increase connectivity between habitat islands. Wildlife corridors can increase the movement of species between parks and reserves and therefore increase the number of species that can be supported, but they can also spread disease and pathogens between populations, complicating the simple issue of connectivity.

In species diversity, island biogeography describes allopatric speciation. Allopatric speciation is where new gene pools arise in isolated gene pools due to natural selection. Island biogeography is also useful in considering sympatric speciation, the idea of different species arising from one ancestral species in the same area.

5.3 Biogeographical Classification Of India

India has different climate and topography in different parts and hence is termed as a mega diversity country. India occupies **10th place among plant rich countries of the world.** Biogeographers have classified India into ten biogeographic zones with each zone having characteristic climate, soil and biodiversity. These zones are described below:

5.3.1Trans-Himalayas: The Trans-Himalayas is an extension to the Tibetean plateau. This region includes the high-altitude cold desert in Ladakh (Jammu and Kashmir) and Lahaul Spiti (Himachal Pradesh). It accounts for 5.7% of the country's landmass.The Himalayan ranges immediately north of the Great Himalayan range are called the Trans- Himalayas. The region is known for hostile climatic conditions and dearth of vegetation. The Trans-Himalayan region with its sparse vegetation has the richest wild sheep and goat community in the world. The snow leopard is found here, as is the migratory black-necked crane.

5.3.2 Himalayas: The Himalayas are the northern boundaries of India. The entire mountain chain is running from Kashmir in the North-west to Assam in the North-east. The Himalayas comprise of a diverse range of biotic provinces and biomes. The Himalayas cover 7.2% of the country's landmass. The Himalayas consist of the youngest and loftiest mountain chains in the world. The Himalayas are unique due to their high altitude, steep gradient and rich temperate flora.

The forests are very dense with extensive growth of grass and evergreen tall trees. Oak, chestnut, conifer, ash, pine, deodar are abundant in Himalayas.

There is no vegetation above the snowline. Several interesting animals live in the Himalayan ranges. Chief species include wild sheep, mountain goats, ibex, shrew, and tapir. Panda and snow leopard are also found here.

5.3.3 Desert: The extremely dry area west of the Aravalli hill range, comprises both the salty desert of Gujarat and the sandy desert of Rajasthan. Deserts occupy around 6.9% of the country's land mass. The kinds of deserts found in India are:

a. The desert of western Rajasthan

b. The desert of Gujarat

The Indian deserts have more diversified fauna. This region consists of parts of Rajasthan, Kutch, Delhi and parts of Gujarat. The climate is characterized by very hot and dry summer and cold winter. Rainfall is less than 30cm. The plants are mostly xerophytic. Babul, cacti, wild palm grows in areas of moderate rainfall. Indian Bustard, a highly endangered bird is found here. Camels, wild asses, foxes, and snakes are found in hot and arid deserts.

5.3.4 Semi-arid: This zone lies between the desert and the Deccan plateau. It includes the Aravalli hill range. It covers approximately 15.6% of the country's landmass. Adjoining the desert are the semi-arid areas, a transitional zone between the desert and the denser forests of the Western Ghats. The natural vegetation is thorny forest. This region is characterized by discontinuous vegetation cover with open areas of bare soil and soil-water deficit throughout the year. Thorny scrubs, grasses and some bamboos are present in some regions. A few species of xerophytic herbs and some ephemeral herbs are found in this semi-arid tract. Vultures, mynas, doves, eagles, tree-pies, jackals, leopards, snakes, fox, and many species of deer are found in this region.

5.3.5 Western Ghats: The western ghats are a mountain range that runs along the western cost of India. They are a range extending north-south from southern tip of Gujarat in the north to Kanyakumari in the south. The mountains cover an area of about 160,000 sq. km. This Ghat section covers an extremely diverse range of biotic provinces and biomes. It covers about 5.8% of the country's landmass. The mountains along the west coast of peninsular India are the Western Ghats, which constitute one of the unique biological regions of the world. The Western Ghats extend from the southern tip of the peninsula (8°N) northwards about 1600 km to the mouth of the river Tapti (21°N).

The mountains rise to average altitudes between 900 and 1500m above sea level, intercepting monsoon winds from the southwest and creating a rain shadow in the region to their East. The varied climate and diverse topography create a wide array of habitats that support unique sets of plant and animal species. Apart from biological diversity, the region boasts of high levels of cultural diversity, as many indigenous people inhabit its forests.

The Western Ghats are amongst the 32 biodiversity hot-spots recognized globally. These hills are known for their high levels of endemism expressed at both higher and lower taxonomic levels. Most of the Western Ghat endemic plants are associated with evergreen forests.

The region also shares several plant species with Sri Lanka. The higher altitude forests are sparsely populated with tribal people. Rice cultivation in the fertile valley is very prominent and commercial crops like areca nut and pepper are also grown here. Expansion of traditional agriculture and the spread of particularly rubber, tea, coffee and forest tree plantations have wiped out large pockets of primary forests in valleys. The Western Ghats are well known for harboring 14 endemic species of caecilians (legless amphibians) out of 15 recorded from the region so far. In addition to this the region is famous for many snake species, lion-tailed macaque, leopard, wolf, fox and many species of birds.

5.3.6Deccan plateau: It is a large triangular plateau south of the Narmada valley. Three sides of the plateau are covered by mountains slopes towards east. Satpura mountains cover the north while western ghats cover the west side and eastern ghats cover the eastern side of the plateau. It is the one of largest zones covering the southern and south-central plateau with mostly deciduous trees. It covers 43% of the country's land mass. Beyond the Ghats is Deccan Plateau, a semi-arid region lying in the rain shadow of the Western Ghats. This is the largest unit of the Peninsular Plateau of India. The highlands of the plateau are covered with different types of forests, which provide a large variety of forest products.

5.3.7Gangetic plains: This plain covers the area between the south Himalayas to the tropic of cancer. These plains were formed by the Ganges river system and are relatively homogeneous. This region experience 600 mm rainfall annually. Sunderbans forests are located in this region and it covers 11% of the country's land mass. In the North is the Gangetic plain extending up to the Himalayan foothills. This is the largest unit of the Great Plain of India. Ganga is the main river after whose name this plain is named.

The thickness in the alluvial sediments varies considerably which is maximum in the Ganga plains. The physiogeographic scenario varies greatly from arid and semi-arid landscapes of the Rajasthan plains to the humid and per-humid landscapes of the Delta and Assam valley in the east.

Topographic uniformity is a common feature throughout these plains. The plain supports some of the highest human population densities of the world, which largely depends upon agro-based economy in some of these areas. The trees belonging to these forests are teak, sal, shisham, mahua, khair etc. The animals of the region include tiger, elephant, monkeys, langurs, deers, peafowl, eagles, prinias, ducks, geese and many raptor species.

5.3.8 North-east India: These are confined to non-himalayan ranges of northeastern India and have a wide variety of vegetation. It covers around 5.2% of the country's land mass. North-east India is one of the richest flora regions in the country. It has several species of orchids, bamboos, ferns and other plants. Here the wild relatives of cultivated plants such as banana, mango, citrus and pepper can be found. Among animals, rhinoceros, elephant, tiger, leopard, deers, snakes, amphibians and vivid bird species are found here.

5.3.9Islands: The Andaman and Nicobar Islands in the Bay of Bengal has almost 300 big and small islands. Among these, only five islands are inhabited. Only tribes are found in the island of Nicobar. These islands have a highly diverse set of biomes and occupy 0.03% of the country's biomass. The two groups of islands, i.e., the Arabian Sea islands and Bay Islands differ significantly in origin and physical characteristics. The Arabian Sea Islands (Lakshadwip, Minicoy, etc.) are the founder remnants of the old land mass and subsequent coral formations. On the other hand, the Bay Islands lay only about 220 km.

Away from the nearest point on the main land mass and extend about 590 km. With a maximum width of 58 km the island forests of Lakshadweep in the Arabian Sea have some of the best-preserved evergreen forests of India. Some of the islands are fringed with coral reefs. Many of them are covered with thick forests and some are highly dissected.

5.3.10Coasts: India has a large coastline distributed both to the east and west with distinct differences between the two.

India has a coastline extending over 5,500 km. The Indian coasts vary in their characteristics and structures. The west coast is narrow except around the Gulf of Cambay and the Gulf of Kutch. In the extreme south, however, it is somewhat wider along the south Sahyadri. The backwaters are the characteristic features of this coast. The east coast plains, in contrast are broader due to depositional activities of the east-flowing rivers owing to the change in their base levels. Extensive deltas of the Mahanadi, Godavari, Krishna and Kaveri are the characteristic features of this coast. Mangrove vegetation is characteristic of estuarine tracts along the coast at Ratnagiri in Maharashtra. Larger parts of the coastal plains are covered by fertile soils on which different crops are grown. Rice is the main crop of these areas. Coconut trees grow all along the coast.

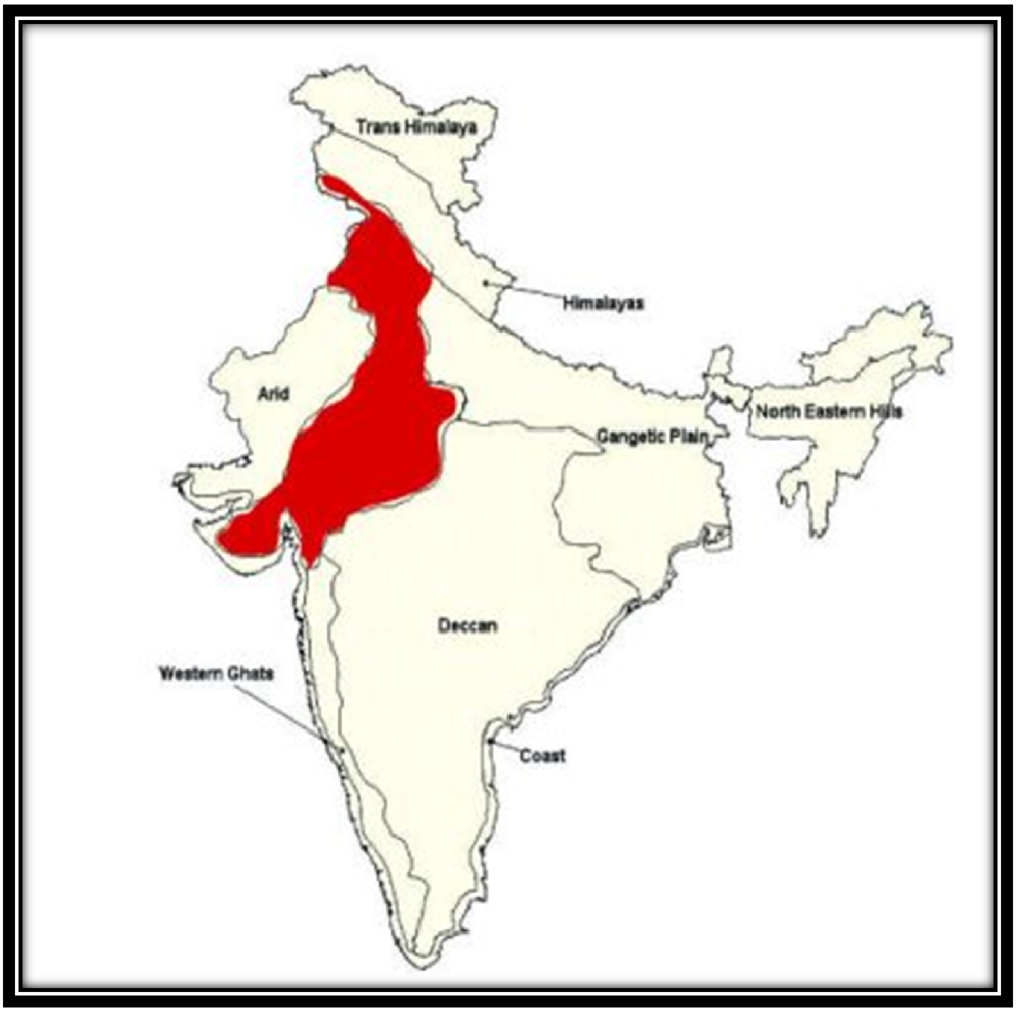


Figure: Biogeographic division of India

5.4 Environmental Pollution

Biosphere is that part of earth where life can exist and it can be divided into three main parts – Lithosphere, Hydrosphere and Atmosphere. Biosphere is constituted by many abiotic and biotic factors, which always remain in homeostasis. The factors which disturb this homeostasis is pollution. Environmental pollution may be defined as the "**unfavourable alteration of our surroundings**". It changes the quality of our air, water and land which interferes with the health of human beings and other life forms on earth. Pollution is of different kinds depending on the nature of pollutant generated from different sources *e.g.* Industry, Automobiles, Thermal power plants, farming and nuclear reactors generate different types of pollutants causing pollution to air, water bodies and land.

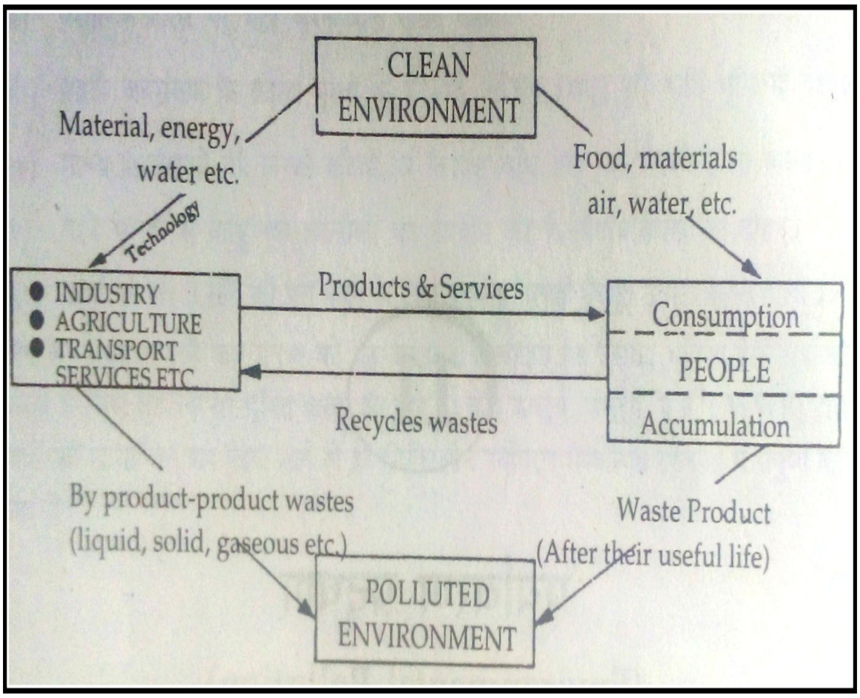


Figure : Environment and pollution

5.5.1 Types of pollutants

Biodegradable pollutants: Those pollutants that degrade or decompose rapidly by natural processes.

Non-biodegradable pollutants: Those pollutants that do not decompose at all or decompose very slowly in the environment.

Different kinds of pollution that affect the environment are:

1. Air pollution
2. Water pollution
3. Soil pollution
4. Insecticide pollution

5. Marine pollution
6. Noise pollution
7. Thermal pollution and
8. Nuclear or radioactive pollution

5.5.2 Air Pollution:

Air is one of the essential elements for life. Animals get oxygen and plants get carbon-di-oxide from air for their survival. Air is present in the atmosphere present in the Troposphere of earth. Air pollution may be defined as the presence of one or more contaminants like dust, harmful gases, mist, smoke and colour in the atmosphere that are injurious human beings, plants and animals. Following factors are mainly responsible for air pollution:

1. Rapid industrialization
2. Fast urbanization
3. Rapid growth in population
4. Growth of vehicles on the roads and
5. Deforestation
6. Anthropogenic activities

The normal composition of the air is shown in the following table:

S. No.	Gas	Per-cent
1	Nitrogen	78%
2	Oxygen	21%
3	Argon	less than 1%
4	Carbondioxide	0.037%
5	Ozone, Helium and ammonia	Trace amount
6	Water vapour	Trace amount

As evident from table Nitrogen and Oxygen are important component of air. Carbon-di-oxide, though present in less quantity, is crucial for the survival of plants. But due to many anthropogenic activities and natural disasters air is getting polluted at an alarming rate. As a consequence many indirect problems, which are threatening the existence of humans, have crept up. The rise in sea level, global warming, coral bleaching, ozone depletion are few such problems which seek urgent human attention. There are many sources of air pollution which are discussed as follows:

5.5.2.1 Sources of Air pollution: Sources of air pollution are of two types. **Natural sources** and **Artificial sources** Natural sources of pollution are those that are caused due to natural phenomena. Ex: Volcanic eruptions, Forest fires, Biological decay, Pollen grains, Marshes, Radioactive materials. Artificial sources are those which are created by man. Ex: Thermal power plants, Vehicular emissions, Fossil fuel burning, agricultural activities etc.

5.5.2.2 Classification of Air Pollutants Depending on the form of pollutants present in the environment**,** they are classified as:

1. Primary pollutants and
2. Secondary pollutants

5.5..2.2.1 Primary pollutants are those that are directly emitted in the atmosphere in the harmful form *e.g.* CO, NO, CO2, SO2 etc. **Indoor air pollutants are primary air pollutants.** The most important indoor air pollutant is **Radon** gas.

Sources of indoor air pollutants are:

1. Radon gas is emitted from building materials like bricks, concrete, tiles, etc that are derived from soil containing radium
2. Radon is also found in natural gas and ground water and is emitted while being used.
3. Burning fuel in the kitchen and cigarette smoke release pollutants like CO, SO_2, HCHO (Formaldehyde) and BAP (Benzo-(A) pyrene).

5.5.2.2.2 Secondary pollutants are those that are formed by reacting with other components or some basic component of the atmosphere to form new pollutants *e.g.* Oxides of Nitrogen (NO_2 or NO_3) react with moisture in the atmosphere to give Nitric acid.

5.5.2.3 Effects of common air pollutants:

Carbonmonoxide: It is a colourless, odourless gas that is poisonous animals. It is formed by incomplete combustion of carbon containing fuels. Source of carbonmonoxide is cigarette smoking and incomplete combustion of fossil fuels (more than 77% comes from motor vehicle exhaust) **Health effects** include reduced ability of red blood cells to carry oxygen to body cells and tissues. This leads to headache and anemia. At high levels it causes coma, irreversible brain damage and death.

Nitrogen Dioxide: It is a reddish-brown irritating gas that causes photochemical smog. In the atmosphere, it gets converted into nitric acid (HNO3). It is caused by burning fossil fuels in industries and power plants.

Health effects include lung irritation and damage. Environmental effects involve acid deposition leading to damage of trees, lakes, soil and ancient monuments. NO2 can damage fabrics. **Sulphur Dioxide**: It is a colourless and irritating gas that is formed by combustion of sulphur containing fossil fuels such as coal and oil. In the atmosphere it is converted into Sulphuric acid which is a major component of acid deposition.

Health effects involve breathing problems for healthy people. **Environmental effects** involve reduced visibility and acid deposition on trees, lakes, soils and monuments leading to their deterioration and adverse effect on aquatic life. **Suspended Particulate Matter (SPM)**: Includes a variety of particles and droplets (aerosols) that can be suspended in atmosphere for short to long periods. Human sources for SPM include burning coal in power and industrial units, burning diesel and other fuels in vehicles, agriculture, unpaved roads, construction, etc. **Health effects** include nose and throat irritation, ling damage, bronchitis, asthma, reproductive problems and cancer. **Environmental Effects** include reduced visibility and acid deposition. Acid deposition may lead to damaged trees, soils and aquatic life in lakes.

Ozone is a highly reactive gas with an unpleasant odour occurring in the stratosphere where it protects mankind from the harmful ultra-violet rays from the Sun. However on earth, it is a pollutant. It occurs on earth due to reaction between Volatile Organic Compounds (VOCs) and Nitrogen Oxides. It moderates the climate

Photochemical smog is a brownish smoke that frequently forms on clear, sunny days over large cities with significant amounts of automobile traffic. It is mainly due to chemical reactions among nitrogen oxides and hydrocarbons in the presence of sunlight. **Health effects** include breathing problems, cough, eye, nose and throat irritation, heart diseases, reduced resistance to colds and pneumonia. Environmental effects involve damage to plants and trees. Additionally, Smog reduces visibility.

Lead is a solid and highly toxic metal. Its compounds are emitted into the atmosphere as particulate matter.

Human Sources: Paint, Smelters (metal refineries), lead manufacture, storage batteries, leaded petrol, etc. **Health effects**: Lead accumulates in the body and brain leading to nervous system damage and mental retardation (especially in children), digestive and other health problems. Lead containing chemicals are known to cause cancer in test animals.
Environmental Effects: It can harm wildlife.

Hydrocarbons Lower haydrocarbons accumulate due to decay of vegetable matter.
Human effects: They are carcinogenic.

Chromium: It is a solid toxic metal emitted into the atmosphere as particulate matter.
Human sources: Paint, Smelters, Chromium manufacture, Chromium plating.
Health Effects: Perforation of nasal septum, chrome holes, etc.

5.5.2.4 Control measures: The atmosphere has several built-in self cleaning processes such as dispersion, gravitational settling, flocculation, absorption, rain-washout, etc to cleanse the atmosphere. However, control of contaminants at their source level is a desirable and effective method through preventive or control technologies.

5.5.2.1 Source control: Some measures that can be adopted in this direction are:

1. Using unleaded petrol
2. Using fuels with low sulphur and ash content
3. Encouraging people to use public transport, walk or use a cycle as opposed to private vehicles
4. Ensure that houses, schools, restaurants and playgrounds are not located on busy streets
5. Plant trees along busy streets as they remove particulates, carbon

dioxide and absorb noise

6. Industries and waste disposal sites should be situated outside the city preferably on the downwind of the city.
7. Catalytic converters should be used to help control emissions of carbon monoxide and hydrocarbons

5.5.4.2 Control measures in industrial centers:

1. Emission rates should be restricted to permissible levels by each and every industry
2. Incorporation of air pollution control equipment in design of plant layout must be made mandatory
3. Continuous monitoring of the atmosphere for pollutants should be carried out to know the emission levels.

5. 4.2.4.3 Equipment used to control air pollution:

1. Air pollution can be reduced by adopting the following approaches.
2. Ensuring sufficient supply of oxygen to the combustion chamber and adequate temperature so that the combustion is complete thereby eliminating much of the smoke consisting of partly burnt ashes and dust.
3. To use mechanical devices such as scrubbers, cyclones, bag houses and electro-static precipitators in manufacturing processes. The equipment used to remove particulates from the exhaust gases of electric power and industrial plants are shown below. All methods retain hazardous materials that must be disposed safely. Wet scrubber can additionally reduce sulphur dioxide emissions.
4. The air pollutants collected must be carefully disposed. The factory fumes are dealt with chemical treatment.

5.4.3 Water pollution

Water pollution may be defined as "the alteration in physical, chemical and biological characteristics of water which may cause harmful effects on humans and aquatic life."

Pollutants include:

1. Sewage
2. Industrial effluents and chemicals

3. Oil and other wastes

Chemicals in air dissolve in rain water, fertilizers, pesticides and herbicides leached from land pollute water.

5.4.3.1 Types, Effects and Sources of Water Pollution: Water pollution is any chemical, biological or physical change in water quality that has a harmful effect on living organisms or makes water unsuitable for desired uses. Infectious agents such as Bacteria, Viruses, Protozoa, and parasitic worms also pollute the water. **Human sources:** Human and animal wastes are also cause of water pollution. **Effects**: Cause variety of diseases.

5.4.3.1.1 Oxygen demanding wastes (Dissolved oxygen): This degradation consumes dissolved oxygen in water. Dissolved Oxygen (DO) is the amount of oxygen dissolved in a given quantity of water at a particular pressure and temperature. The saturated point of DO varies from 8 to 15 mg/L. Organic wastes such as animal manure and plant debris that can be decomposed by aerobic (oxygen-requiring) bacteria. **Human sources**: Sewage, Animal wastes, paper mills and food processing industries' wastes. **Effects**: Large populations of bacteria decomposing these wastes can degrade water quality by depleting water of dissolved oxygen. This causes fish and other forms of oxygen-consuming aquatic life to die.

5.4.3.1.2 Inorganic chemicals: Water soluble inorganic chemicals – Acids, Compounds of toxic metals such as lead (Pb), arsenic (As) and selenium (Se) and salts such as NaCl in oceans and fluoride (F) found in some soils – are major source of this kind of pollution. **Human sources**: Surface runoff, industrial effluents and household cleansers. **Effects:** Inorganic chemicals can: Make freshwater unusable for drinking and irrigation, Cause skin cancer and neck damage, Damage nervous system, liver and kidneys, Harm fishes and other aquatic life, Lower crop yields, Accelerate corrosion of metals exposed to such water.

5.4.3.1.3 Organic chemicals: Oil, Gasoline, Plastics, Pesticides, Cleaning solvents and Detergents are the common organic compounds that pollute the water. **Human Sources**: Industrial effluents, household cleansers and surface runoff from farms. **Effects**: Can threaten human health by causing nervous system damage and some cancers. Harm fish and wildlife.

5.4.3.1.4 Plant nutrients: Water soluble compounds containing nitrate, Phosphate and Ammonium ions are important plant nutrients that cause water pollution. **Human sources**: Sewage, manure and runoff of agricultural and urban fertilizers. **Effects:** Can cause excessive growth of algae and other aquatic plants, which die, decay and deplete dissolved oxygen in water thereby killing fish. Drinking water with excessive levels of nitrates, lowers the oxygen carrying capacity of the blood and can kill urban children and infants.

5.4.3.1.5 Sediments: Soil, silt, etc. are important sediments that cause water pollution. **Human Sources:** Land erosion. **Effects:** Causes cloudy water thereby reducing photosynthetic activity, Disruption of aquatic food chain, Carries pesticides, bacteria and other harmful substances, Settles and destroys feeding and spawning grounds of fish, Clogs and fills lakes, artificial reservoirs, stream channels and ports.

5.4.3.1.6 Radioactive materials: Radioactive isotopes of Iodine, Radon, Uranium, Cesium and Thorium are important water contaminants. **Human sources**: Nuclear power plants, mining and processing of uranium and other ores, nuclear weapon production and natural sources. **Effects**: Genetic mutations, birth defects and certain cancers.

5.4.3.1.7 Heat (Thermal pollution): Water used for cooling the excessive heat generated in industry and nuclear station and subsequent release of hot water in the rivers and lakes is main cause of thermal pollution. **Human sources**: Water cooling of electric power plants and some types of industrial plants. **Effects:** Low dissolved oxygen levels thereby making aquatic organisms more vulnerable to disease, parasites and toxic chemicals. When a power plant starts or shuts down for repair, fish and other organisms adapted to a particular temperature range, can be killed by an abrupt temperature change known as thermal shock.

5.4.3.2 Point and non-point sources of water pollution:

Point sources: These are pollutants that are discharged at specific locations through pipes, ditches or sewers into bodies of surface waters. Ex: Factories, sewage treatment plants, abandoned underground mines and oil tankers.

Non point sources: These pollutants cannot be traced to a single point of discharge. They are large land areas or air-sheds that pollute water by runoff, subsurface flow or deposition from the atmosphere. Ex: Acid deposition, runoff of chemicals into surface water from croplands, livestock feedlots, logged forests, urban streets, lawns, golf courses and parking lots.

5.4.3.3 Control measures:

1. Administration of water pollution control should be in the hands of state or central government
2. Scientific techniques should be adopted for environmental control of catchment areas of rivers, ponds or streams
3. Industrial plants should be based on recycling operations as it helps prevent disposal of wastes into natural waters but also extraction of products from waste.
4. Plants, trees and forests control pollution as they act as natural air conditioners.
5. Trees are capable of reducing sulphur dioxide and nitric oxide pollutants and hence more trees should be planted.
6. No type of waste (treated, partially treated or untreated) should be discharged into any natural water body. Industries should develop closed loop water supply schemes and domestic sewage must be used for irrigation.
7. Qualified and experienced people must be consulted from time to time for effective control of water pollution.
8. Public awareness must be initiated regarding adverse effects of water pollution using the media.
9. Laws, standards and practices should be established to prevent water pollution and these laws should be modified from time to time based on current requirements and technological advancements.
10. Basic and applied research in public health engineering should be encouraged.

5.4.4 Soil pollution

Soil pollution is defined as, "contamination of soil by human and natural activities which may cause harmful effect on living organisms". Composition of soil is listed below in the table:

S. No.	**Component**	**%**
1	Organic mineral matter	45
2	Organic matter	05
3	Soil water	25
4	Soil air	25

5.4.4.1 Soil Pollutants

Soil pollution mainly occurs due to the following:

1. Industrial wastes
2. Urban wastes
3. Agricultural practices
4. Radioactive pollutants
5. Biological agents

5.4.4.1.1 Industrial wastes: Disposal of Industrial wastes is the major problem for soil pollution. **Sources**: Industrial pollutants are mainly discharged from various origins such as pulp and paper mills, chemical fertilizers, oil refineries, sugar factories, tanneries, textiles, steel, distilleries, fertilizers, pesticides, coal and mineral mining industries, drugs, glass, cement, petroleum and engineering industries etc. **Effect:** These pollutants affect and alter the chemical and biological properties of soil. As a result, hazardous chemicals can enter into human food chain from the soil or water, disturb the biochemical process and finally lead to serious effects on living organisms.

5.4.4.1.2 Urban wastes: Urban wastes comprise of both commercial and domestic wastes consisting of dried sludge and sewage. All the urban solid wastes are commonly referred to as refuse. **Constituents of urban refuse**: This refuse consists of garbage and rubbish materials like plastics, glasses, metallic cans, fibres, paper, rubbers, street sweepings, fuel residues, leaves, containers, abandoned vehicles and other discarded manufactured products. Urban domestic wastes though disposed off separately from industrial wastes, can still be dangerous. This happens because they are not easily degraded.

5.4.4.1.3Agricultural practices: Modern agricultural practices pollute the soil to a large extent. With the advancing agro-technology, huge quantities of fertilizers, pesticides, herbicides and weedicides are added to increase the crop yield. Apart from these farm wastes, manure, slurry, debris, soil erosion containing mostly inorganic chemicals are reported to cause soil pollution.

5.4.4.1.4 Radioactive pollutants: Radioactive substances resulting from explosions of nuclear testing laboratories and industries giving rise to nuclear dust radioactive wastes, penetrate the soil and accumulate giving rise to land/soil pollution. Ex: Radio nuclides of Radium, Thorium, Uranium, isotopes of Potassium (K-40) and Carbon (C-14) are commonly found in soil, rock, water and air. Explosion of hydrogen weapons and cosmic radiations include neutron, proton reactions by which Nitrogen (N-15) produces C-14. This C-14 participates in Carbon metabolism of plants which is then into animals and human beings. Radioactive waste contains several radio nuclides such as Strontium90, Iodine-129, Cesium-137 and isotopes of Iron which are most injurious. Strontium get deposited in bones and tissues instead of calcium. Nuclear reactors produce waste containing Ruthenium-106, Iodine-131, Barium-140, Cesium-144 and Lanthanum-140 along with primary nuclides Sr-90 with a half life 28 years and Cs-137 with a half life 30 years. Rain water carries Sr-90 and Cs-137 to be deposited on the soil where they are held firmly with the soil particles by electrostatic forces. All the radio nuclides deposited on the soil emit gamma radiations.

5.4.4.1.5 Biological agents: Soil gets a large amount of human, animal and bird excreta which constitute a major source of land pollution by biological agents. Ex: 1. Heavy application of manures and digested sludge can cause serious damage to plants within a few years

5.4.4.2.1 Control measures of soil pollution:

4.4.2.1 **Prevention of soil erosion:** Soil erosion can be controlled by a variety of forestry and farm practices. Ex: Planting trees on barren slopes, Contour cultivation and strip cropping may be practiced instead of shifting cultivation, Terracing and building diversion channels may be undertaken. Reducing deforestation and substituting chemical manures by animal wastes also helps arrest soil erosion in the long term.

4.4.2.2 **Proper dumping of unwanted materials:** Excess wastes by man and animals pose a disposal problem. Open dumping is the most commonly practiced technique. Nowadays, controlled tipping is followed for solid waste disposal. The surface so obtained is used for housing or sports field.

4.4.2.3 **Production of natural fertilizers**: Bio-pesticides should be used in place of toxic chemical pesticides. Organic fertilizers should be used in place of synthesized chemical fertilizers.

Ex: Organic wastes in animal dung may be used to prepare compost manure instead of throwing them wastefully and polluting the soil.

4.4.2.4 **Proper hygienic condition**: People should be trained regarding sanitary habits. Ex: Lavatories should be equipped with quick and effective disposal methods.

4.4.2.5 **Public awareness**: Informal and formal public awareness programs should be imparted to educate people on health hazards by environmental education. Ex: Mass media, Educational institutions and voluntary agencies can achieve this.

4.4.2.6 **Recycling and Reuse of wastes:** To minimize soil pollution, the wastes such as paper, plastics, metals, glasses, organics, petroleum products and industrial effluents etc should be recycled and reused. Ex: Industrial wastes should be properly treated at source. Integrated waste treatment methods should be adopted.

4.4.2.7 **Ban on Toxic chemicals:** Ban should be imposed on chemicals and pesticides like DDT, BHC, etc which are fatal to plants and animals. Nuclear explosions and improper disposal of radioactive wastes should be banned.

5.4.5 Noise pollution

Noise is defined as, "the unwanted, unpleasant or disagreeable sound that causes discomfort to all living beings". Sound intensity is measured in decibels (dB), that is the tenth part of the longest unit Bel. One dB is the faintest sound that a human ear can hear.

5.4.5.1 Types of noise: Environmental noise has been doubling every ten years. Noise is classified as:

1. Industrial Noise
2. Transport Noise and
3. Neighbourhood noise

5.4.5.1.1 Industrial Noise: It is sound with a high intensity sound caused by industry machines. Sources of such noise pollution is caused by machines from machines in various factories, industries and mills. Noise from mechanical saws and pneumatic drills is unbearable and a nuisance to the public. The Indian Institute of Oto-Rino Laryngology, Chennai reported that increasing industrial pollution damages the hearing ability by atleast 20%. Workers in steel industry, who work close to heavy industrial blowers are exposed to 112dB for eight hours suffer from occupational pollution.

5.4.5.1.2 Transport Noise: Transport noise mainly consists of traffic noise from road, rail and aircraft. The number of automobiles on roads like motors, scooters, cars, motor cycles, buses, trucks and diesel engine vehicles have increased enormously in the recent past further aggravating the problem of transport noise. Noise levels in most residential areas in metropolitan cities is hovering around the border line due to increased vehicular noise pollution. This high level of noise pollution leads to deafening in the elderly.

5.4.5.1.3 Neighbourhood noise: This type of noise includes disturbance from household gadgets and community. Common sources being musical instruments, TV, VCR, Radios, Transistors, Telephones, and loudspeakers etc. Statistically, ever since the industrial revolution, noise in the environment has been doubling every ten years.

5.4.5.2 Effects of Noise pollution

1. Noise pollution affects both human and animal health. It leads to:
    a. contraction of blood vessels
    b. making skin pale
    c. excessive adrenalin in the blood stream which is responsible for high blood pressure.
    d. Blaring sounds are known to cause mental distress
    e. Heart attacks, neurological problems, birth defects and abortion
2. Muscle contraction leading to nervous breakdown, tension, etc
3. The adverse reactions are coupled with a change in hormone

   content of blood, which in-turn increases heart beat, constriction of blood vessels, digestive spams and dilation of the pupil of the eye.
4. Adverse affects health, work efficiency and behaviour. Noise

   pollution may cause damage to the heart, brain, kidneys, liver and may produce emotional disturbance.

5. The most immediate and acute effect of noise is impairment of hearing that diminishes some part of the auditory system. Prolonged exposure to noise of certain frequency pattern leads to chronic damage to the inner ear.
6. Impulsive noise may cause psychological and pathological disorders
7. Ultrasonic sound can affect the digestive, respiratory, cardiovascular system and semicircular canals of the internal ear.
8. The brain is adversely affected by loud and sudden noise by jets and airplanes. People are subjected to psychiatric illness.
9. Recent reports suggest that blood is thickened by excessive noise.
10. The optical system of human beings is also affected by noise pollution. Severe noise pollution causes:
    a. Pupullary dilation
    b. Impairment of night vision and
    c. Decrease in rate of colour perception

5.4.5.3 Control measures:

1. **Source control:** This includes source modification such as acoustic treatment to machine surface, design changes, limiting operational timings, etc
2. **Transmission path intervention**: This includes containing the source inside a sound insulating enclosure, constructing a noise barrier or provision of sound absorbing materials along the path.
3. **Receptor control:** This includes protection of the receiver by altering the work schedule or provision of personal protection devices such as ear plugs for operating noisy machinery. The measure may include dissipation and deflection methods.
4. **Oiling:** Proper oiling will reduce noise from the machine.

Preventive measures:

1. Prescribing noise limits for vehicular traffic
2. Ban on honking (usage of horns) in certain areas

3. Creation of silence zones near schools and hospitals
4. Redesigning buildings to make them noise proof
5. Reduction of traffic density in residential areas
6. Giving preference to mass public transport system.

5.6 Nuclear Pollution

Radionuclides are elements (uranium 235, uranium 283, thorium 232, potassium 40, radium 226, carbon 14 etc.) with unstable atomic nuclei and on decomposition release ionizing radiations in the form of alpha, beta and gamma rays. Out of the known 450 radioisotopes only some are of environmental concern like strontium 90, tritium, plutonium 239, argon 41, cobalt 60, cesium 137, iodine 131, krypton 85 etc. These can be both beneficial and harmful, depending on the way in which they are used.

X-rays are used in routine to examine bones for fractures, Gamma radiations are used to treat cancer and many other radio-active isotopes are used to diagnose diseases. About 17% of the electrical energy generated in the world comes from nuclear power plants.

5.6.1 Sources of Nuclear Pollution: Radioactive substances when released into the environment are either dispersed or become concentrated in living organisms through the food chain. Other than naturally occurring radioisotopes, significant amounts are generated by human activity, including the operation of nuclear power plants, the manufacture of nuclear weapons, and atomic bomb testing. For example, strontium 90 behaves like calcium and is easily deposited and replaces calcium in the bone tissues. It could be passed to human beings through ingestion of strontium-contaminated milk. Again another example is tritium, which is radioactive hydrogen. The amount of tritium released from nuclear power plants to the atmosphere have reached as high as tens of thousands of curies in one year, and releases to bodies of water have measured as high as tens of millions of picocuries per litre. The U.S. Environmental Protection Agency standard for permissible levels of tritium in drinking water is 20,000 picocuries per litre.

Nuclear power plants routinely and accidentally release tritium into the air and water. Tritium has a half-life of 12.3 years and emits radioactive beta particles. Once tritium is inhaled or swallowed, its beta particles can bombard cells causing a mutation.

The sources of radioactivity include both natural and manmade.

5.6.2 Effects of Nuclear Radiations: Few occupations that involve radioactive exposures are uranium mineworkers, radium watch dial painters, technical staff at nuclear power plants, etc. Exposure to radioactive and nuclear hazards has been clinically proven to cause cancer, mutations and teratogenesis (a prenatal toxicity characterized by structural or functional defects in the developing embryo or fetus).

Nuclear hazard effects can be either initial or residual. Initial effects occur in the immediate area of explosion and are hazardous immediately after the explosion where as the residual effects can last for days or years and cause death. The principal initial effects are blast and radiation. Blast causes damage to lungs, ruptures eardrums, collapses structures and causes immediate death or injury. Thermal Radiation is the heat and light radiation, which a nuclear explosion’s fireball emits producing extensive fires, skin burns, and flash blindness. Nuclear radiation consists of intense gamma rays and neutrons produced during the first minute after the explosion.

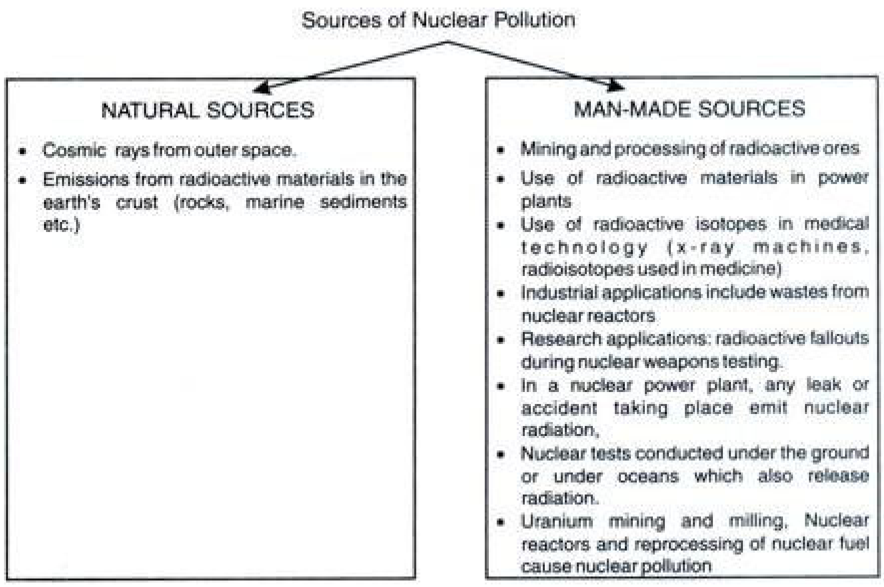
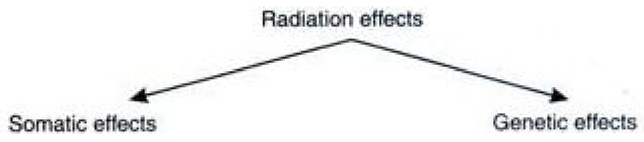


Figure: Natural and man-made sources of Nuclear Pollution

This radiation causes extensive damage to cells throughout the body. Radiation damage may cause headaches, nausea, vomiting, diarrhea, and even death, depending on the radiation dose received.

Studies have shown that the health effects due to radiation are dependent on the level of dose, kind of radiation, duration of exposure and types of cells irradiated. Radiation effects can be somatic or genetic.



5.6.2.1 Somatic effects: Somatic effects the function of cells and organs. It causes damages to cell membranes, mitochondria and cell nuclei resulting in abnormal cell functions, cell division, growth and death.

5.6.2.2 Genetic effects: Genetic effects the future generations. Radiations can cause mutations, which are changes in genetic makeup of cells. These effects are mainly due to the damages to DNA molecules. People suffer from blood cancer and bone cancer if exposed to doses around 100 to 1000 roentgens. Instantaneous deaths on exposure in the event if disasters are many.

5.6.3 Management of Radioactive Waste:

a. The radioactive waste which comes out from industry, nuclear reactors should be stored and allowed to decay either naturally in closed drums or in very large underground air tight cemented tanks (Delay and Decay).

b. The intermediate radioactive waste should be disposed off into the environment after diluting it with some inert materials (Dilute and Disperse)

c. Now-a-days small quantities of high activity wastes are converted into solids such as concrete and then it is buried underground or sea. (Concentrate and contain)

5.6.4 Control Measures:

a. Laboratory generated nuclear wastes should be disposed off safely and scientifically.

b. Nuclear power plants should be located in areas after careful study of the geology of the area, tectonic activity and meeting other established conditions.

c. Appropriate protection against occupational exposure.

d. Leakage of radioactive elements from nuclear reactors, careless use of radioactive elements as fuel and careless handling of radioactive isotopes must be prevented.

e. Safety measure against accidental release of radioactive elements must be ensured in nuclear plants.

f. Unless absolutely necessary, one should not frequently go for diagnosis by x-rays.

g. Regular monitoring of the presence of radioactive substance in high risk area should be ensured.

Among the many options for waste disposal, the scientists prefer to bury the waste in hundreds of meters deep in the earth's crust is considered to be the best safety long term option.

5.5 Global Environmental Changes

Environment is dynamic in nature and keeps on changing with time. Earth has faced five glaciations in the past and all of them led to mass extinction of flora and fauna. Now our planet is witnessing phenomenon of global warming and many anthropogenic factors are mainly responsible for it. El Nino, La Nina, Tsunami, earthquakes bring massive changes in the environment. These are discussed here.

5.5.1 El Nino

Various kind of oceanic movements are categorized as currents. It is the air blowing over the surface of water that causes the major surface currents. The heat stored in the oceans significantly affects the air circulation. The general circulation of the oceanic water is pole-ward flow of the warm water along the edge of each ocean basin. There is an equator-ward movement of the cool water from high latitude along the eastern margin of each ocean basin. Any disturbance in the ocean temperature causes El Nino and La Nina effects.

In Spanish, the term "El Nino" refers to the Christ child, Jesus (literal translation "The (male) Child"). La Nina, chosen as the 'opposite' of El Nino, literally means "The (female) Child". El Nino was so named because periodic warming in the Pacific near South America is often noticed around Christmas.

The effects of El Nino are likely to develop over North America during the upcoming winter season. Those include warmer-than-average temperatures over western and central Canada, and over the western and northern United States. Wetter conditions are likely over portions of the U.S. Gulf Coast and Florida, while drier conditions can be expected in the Ohio Valley and the Pacific Northwest.

The traditional, also called Eastern Pacific (EP) El, involves temperature anomalies in the Eastern Pacific. However, in the last two decades, nontraditional Els were observed, in which the usual place of the temperature anomaly is not affected, but an anomaly arises in the central Pacific. The phenomenon is called Central Pacific (CP) El , "dateline" El (because the anomaly arises near the dateline), or El "Modoki" (Modoki is Japanese for "similar, but different").

The effects of the CP El Nino are different from those of the traditional EP El — *e.g.*, the recently discovered El leads to more hurricanes more frequently making landfall in the Atlantic.

The first recorded El that originated in the central Pacific and moved toward the east was in 1986. Recent Central Pacific Els happened in 1986–1987, 1991–1992, 1994–1995, 2002–2003, 2004–2005, 2009–2010 and 2013-14.

El Nino is the warm phase of the El Nino Southern Oscillation (commonly called ENSO) and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific. El Nino Southern Oscillation refers to the cycle of warm and cold temperatures, as measured by sea surface temperature (SST) of the tropical central and eastern Pacific Ocean. El Nino is accompanied by high air pressure in the western Pacific and low air pressure in the eastern Pacific. The cool phase of ENSO is called "La Nina" with SST in the eastern Pacific below average and air pressures high in the eastern and low in western Pacific. The ENSO cycle, both El Nino and La Nina, causes global changes of both temperatures and rainfall. Mechanisms that cause the oscillation remain under study.

Developing countries dependent upon agriculture and fishing, particularly those bordering the Pacific Ocean, are the most affected by El.

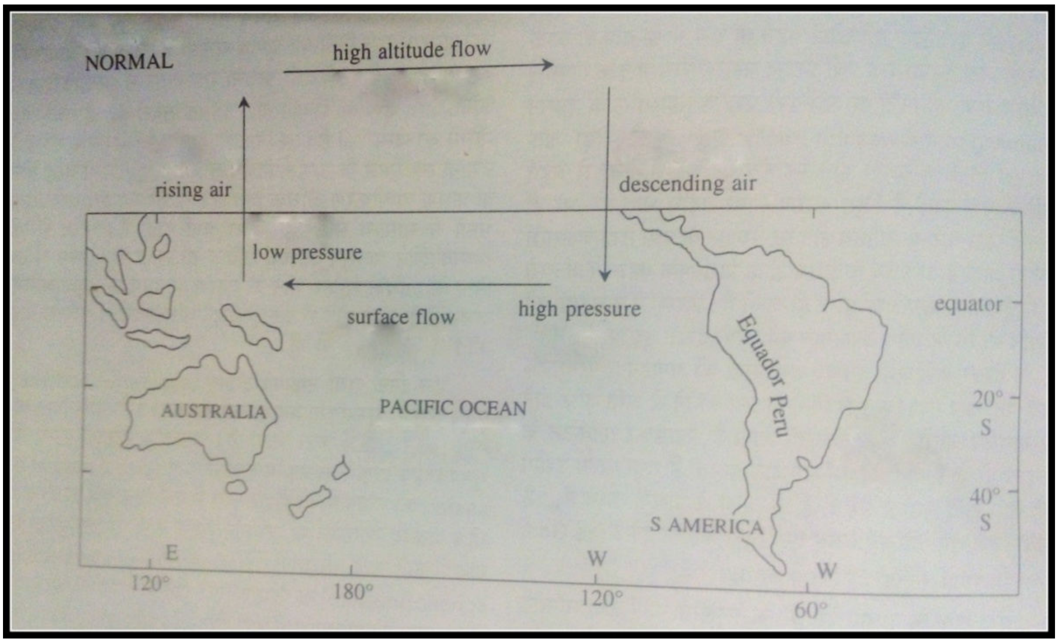


Figure: Air flow during normal year

5.1.1 Definition:

El Nino is defined by prolonged warming in the Pacific Ocean SST when compared with the average value. Typically, this abnormality in temperature happens at irregular intervals of two to seven years, and lasts for a period of nine months to two years. The average period length is five years. When this warming occurs for seven to nine months, it is classified as **El Nino "conditions"**; when its duration is longer, it is classified as an **El Nino "episode"**. The first signs of an El Nino are: 1. Rise in surface pressure over the Indian Ocean, Indonesia, and Australia, 2. Fall in air pressure over central and eastern Pacific Ocean, 3. Trade winds in the south Pacific weaken or head east, 4. Warm air rises near Peru, causing rain in the northern Peruvian state.

More generally, El Nino can affect commodity prices and the macroeconomy of different countries – and not always for the worst. It limits the supply of rain-driven agricultural commodities; reduces agricultural output, construction and services activities are hampered; food-price and generalized inflation are witnessed; and may trigger social unrest in commodity-dependent poor countries that primarily rely on imported food. While Australia, Chile, Indonesia, India, Japan, New Zealand and South Africa face a short-lived fall in economic activity in response to an El Nino shock, other countries may actually benefit from an El Nino.

5.1.1 Effects of ENSO warm phase (El Nino)

5.1.1.1 Changed rainfall patterns

Because El Nino's warm pool feeds thunderstorms above, it creates increased rainfall across the east-central and eastern Pacific Ocean, including several portions of the South American west coast. The effects of El Nino in South America are direct and stronger than in North America. Along the west coast of South America, El Nino reduces the upwelling of cold, nutrient-rich water that sustains large fish populations.

The ENSO variability may contribute to the great success of small, fast-growing species along the Peruvian coast, as periods of low population removes predators in the area. Similar effects benefit migratory birds that travel each spring from predator-rich tropical areas to distant winter-stressed nesting areas.

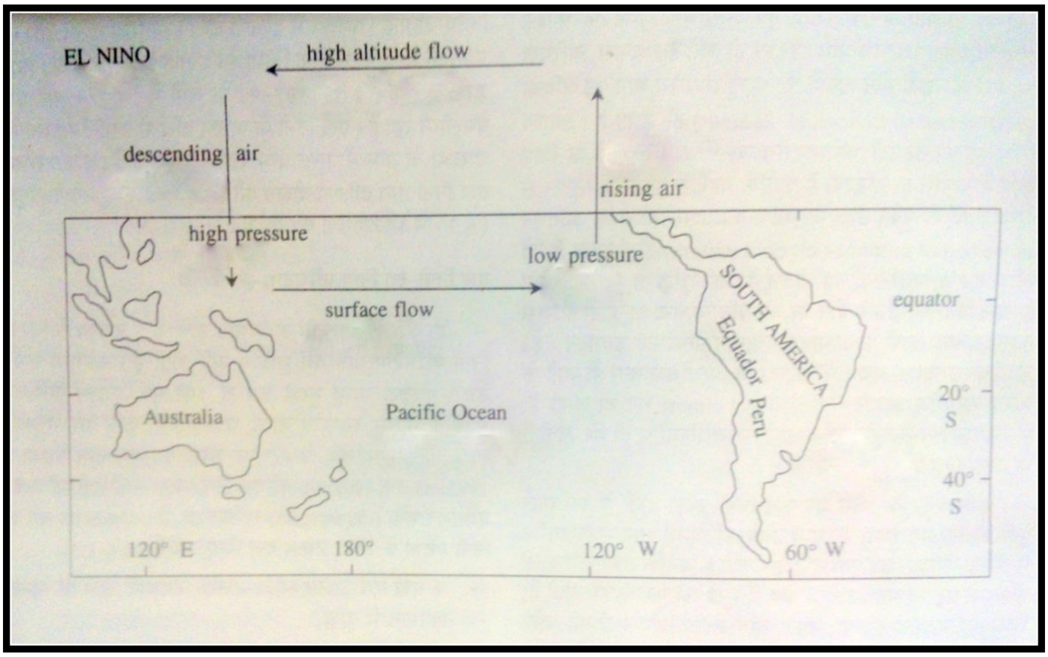


Figure: Air flow during El Nino year

5.1.2.2 Tropical cyclones

The tropical Atlantic ocean experiences depressed activity due to increased vertical wind shear across the region during El Nino years. On the otherhand, the tropical Pacific Ocean east of the dateline has above-normal activity during El Nino years due to water temperatures well above average and decreased wind cut-off. Most of the recorded East Pacific category 5 hurricanes occur during El Nino years in clusters.

El Nino's effects on Europe appear to be strongest in winter. El Nino causes a colder, drier winter in Northern Europe and a milder, wetter winter in Southern

Europe. As warm water spreads from the west Pacific and the Indian Ocean to the east Pacific, it takes the rain with it, causing extensive drought in the western Pacific and rainfall in the normally dry eastern Pacific.

5.1.2.3 Health and social impacts

Extreme weather conditions related to the El Nino cycle correlate with changes in the incidence of epidemic diseases. For example, the El Nino cycle is associated with increased risks of some of the diseases transmitted by mosquitoes, such as malaria, dengue, and Rift Valley fever. Cycles of malaria in India, Venezuela, Brazil, and Colombia have now been linked to El Nino. Outbreaks of another mosquito-transmitted disease, Australian encephalitis, also known as Murray Valley encephalitis, occur in temperate south-east Australia after heavy rainfall and flooding, which are associated with La Nina events. ENSO conditions have also been related to Kawasaki disease incidence in Japan and the west coast of the United States, via the linkage to tropospheric winds across the north Pacific Ocean.

5.1.2.4 Transitional phases

Transitional phases at the onset or departure of El Nino or La Nina can also be important factors on global weather by affecting tele-connections. Significant episodes, known as Trans-Nino, are measured by the Trans-Nino index (TNI). Examples of affected short-time climate in North America include precipitation in the Northwest US and intense tornado activity in the US.

5.1.2.5 Global Warming

During the last several decades the number of El Nino events increased, although a much longer period of observation is needed to detect robust changes. The question arises, whether this is random fluctuation or a normal instance of variation for that phenomenon or the result of global climate changes as a result of global warming. A robust tendency to increase in extreme El Ninos was reported in the renowned journal Nature in 2014.

Several studies of historical data suggest the recent El Nino variation is linked to global warming but there is no consensus on this aspect. It may be that the observed phenomenon of more frequent and stronger El Nino events occurs only in the initial phase of the global warming, and then (e.g., after the lower layers of the ocean get warmer, as well), El Nino will become weaker than it was. It may also be that the stabilizing and destabilizing forces influencing the phenomenon will eventually compensate for each other. More research is needed to provide a better answer to that question. However, new models published in Nature 2014 indicated unmitigated global warming would particularly affect the surface waters of the eastern equatorial Pacific and double extreme El Nino occurrence.

ENSO conditions have occurred at two to seven year intervals for at least the past 300 years, but most of them have been weak. The extreme weather produced by El Nino in 1876–77 gave rise to the most deadly famines of the 19th century. The 1876 famine alone in northern China killed up to 13 million people.

The major 1982–83 El Nino led to an upsurge of interest from the scientific community. The period 1991–1995 was unusual in that El Ninos have rarely occurred in such rapid succession. An especially intense El Nino event in 1998 caused an estimated 16% of the world's reef systems to die. The event temporarily warmed air temperature by 1.5 °C, compared to the usual increase of 0.25 °C associated with El Nino events. Since then, mass coral bleaching has become common worldwide, with all regions having suffered "severe bleaching".

Major ENSO events were recorded in the years 1790–93, 1828, 1876–78, 1891, 1925–26, 1972–73, 1982–83 and 1997–98, with 1997-1998 episode being one of the strongest ever.

5.2 La Nina

La Nina means "*The Little Girl"* in Spanish. La Nina is also sometimes called *El Viejo*, *anti-El* , or simply "*a cold event.*" La Nina was first observed in the year 1986 and name La was given in the same year. La Nina has been found to be active during the years – 1950-51, 1954-56,1964-65, 1970-72, 1973-74, 1974-76, 1984-85, 1988-89, 1995-96, 1998-2000, 2005-06, 2007-09, 2010-12.

La Nina episodes represent periods of below-average sea surface temperatures across the east-central Equatorial Pacific. Global climate La Nina impacts tend to be opposite those of El impacts. In the tropics, ocean temperature variations in La Nina also tend to be opposite those of El. During a La Nina year, winter temperatures are warmer than normal in the Southeast and cooler than normal in the Northwest.

The traditional La Nina, also called Eastern Pacific (EP) La Nina, involves temperature anomalies in the Eastern Pacific. However, in the last two decades, nontraditional La Nina were observed, in which the usual place of the temperature anomaly is not affected, but an anomaly arises in the central Pacific. The phenomenon is called Central Pacific (CP) La Nina, "dateline" (because the anomaly arises near the dateline), or La Nina "Modoki" (Modoki in Japanese means "similar, but different"). The effects of the CP La Nina are different from those of the traditional EP La Nina—*e.g.*, the new La Nina leads to a rainfall increase over northwestern Australia and northern Murray-Darling basin, rather than over the east as in a conventional La Nina. Also, La Nina Modoki increases the frequency of cyclonic storms over Bay of Bengal, but decreases the occurrence of severe storms in the Indian Ocean.

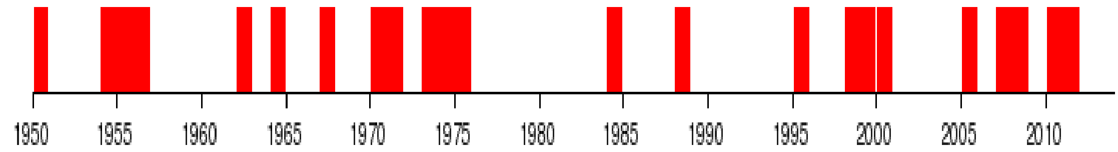
There is also a scientific debate on the very existence of this "new" ENSO. A number of studies dispute the reality of this statistical distinction or its increasing occurrence, or both, either arguing the reliable record is too short to detect such a distinction, finding no distinction or trend using other statistical approaches, or that other types should be distinguished, such as standard and extreme ENSO.

5.2.1 Occurrences

There was a relatively strong La Nina episode during 1988–1989. La Nina also formed in late 1983, in 1995, and a protracted La Nina event that lasted from mid-1998 through early 2001. This was followed by a neutral period between 2001 and 2002. The La Nina which developed in mid-2007 and lasted until almost 2009, was a moderate one. The strength of the La Nina made the 2008 Atlantic hurricane season one of the five most active since 1944; 16 named storms had winds of at least 39 mph (63 km/h), eight of which became 74 mph (119 km/h) or greater hurricanes.

A new La Nina episode developed quite quickly in the eastern and central tropical Pacific in mid-2010, and lasted until early 2011. It intensified again in the mid-2011 and lasted until early 2012 This La Nina, combined with record-high ocean temperatures in the north-eastern Indian Ocean, has been a large factor in the 2010–2011 Queensland floods, and the recent heavy snowstorms in North America. The same La Nina event is also a likely cause of a series of tornadoes of above-average severity that struck the Midwestern and Southern United States in the spring of 2011, and is currently a major factor for the drought conditions persisting in the South Central states including Texas, Oklahoma and Arkansas. Meanwhile, a series of major storms caused extensive flooding in California in December 2010, with seven consecutive days of non-stop rainfall, leading to one of the wettest Decembers in over 120 years of records. This is in contrast to the drier-than-normal conditions typically associated with La Nina in California.

La Nina contributed to severe drought in East Africa and to Australia's third wettest year in its 112-year period of records. La Nina events between 1950 and 2014 are shown in the following figure:



5.6 Natural Disasters

India, due to its geographical locations and geological formations, is a highly disaster prone country. Its long coastline, snow-covered high peaks, high mountain ranges, the perennial rivers in the north all combine to add to this problem. India, which has only two per cent the total geographical area, has to support 16 percent of total world population. Naturally, there is a tremendous pressure on the natural resources, which directly or indirectly lead to the occurrence of disasters, namely floods, droughts, landslides, earthquakes, *etc*.

India has faced a number of disasters, ranging from flood, earthquakes, cyclones, tsunami, drought, landslides. A few recent disasters faced by India include Uttar Kasha earthquake in UP in 1991. Later earthquake in Maharashtra in 1993, Chama earthquake in Gujarat, super cyclone in Orissa in 1999, Buhl earthquake in Gujarat in 2001, Tsunami in 2004 and Mumbai-Gujarat flood in 2005. Besides, India has a bad experience of technology-related tragedy in the form of gas tragedy in Bhopal in 1984. India also faced the problem of Plague in Gujarat.

5.7 Types of Disasters

A disaster is a natural or man-made hazard causing significant physical damage or destruction, loss of life, or drastic change to the environment. A disaster can be defined as any tragic event stemming from events such as earthquakes, floods, catastrophic accidents, fires, or explosions. It is a phenomenon that can cause damage to life and property and destroy the economic, social and cultural life of people.

5.6.1 Hazards are divided into natural or human-made:

A **natural disaster** is a consequence when a natural hazard affects humans and/or the environment. Various phenomena like earthquakes, landslides, volcanic eruptions, floods and cyclones are all natural hazards that kill thousands of people and destroy crores of rupees of living environment and property each year. Developing countries suffer more or less chronically by natural disasters. Asia tops the list of casualties due to natural disasters.

Man-made disasters are the consequence of technological or human hazards. Examples are stampedes, fires, transport accidents, oil and chemical spills, nuclear radiations and wars.

5.6.2 EARTHQUAKES

An **earthquake** (also known as a **quake**, **tremor** or **temblor**) is the shaking of the surface of the Earth, which can be violent enough to destroy major buildings and kill thousands of people. The severity of the shaking can range from barely felt to violent enough to toss people around. Earthquakes have destroyed whole cities. They result from the sudden release of energy in the Earth's crust that creates seismic waves. The **seismicity**, **seismism** or **seismic activity** of an area refers to the frequency, type and size of earthquakes experienced over a period of time.

Earthquakes are measured using observations from seismometers. The moment magnitude is the most common scale on which earthquakes larger than approximately 5 are reported for the entire globe. The more numerous earthquakes smaller than magnitude 5 reported by national seismological observatories are measured mostly on the local magnitude scale, also referred to as the **Richter magnitude scale**. These two scales are numerically similar over their range of validity. Magnitude 3 or lower earthquakes are mostly weak and magnitude 7 and over potentially cause serious damage over larger areas, depending on their depth. The largest earthquakes in historic times have been of magnitude slightly over 9, although there is no limit to the possible magnitude. The most recent large earthquake of magnitude 9.0 hit Japan in 2011 and the largest Japanese earthquake of above 9 magnitude was observed in 2014 and is considered largest since recording of earthquakes began. Intensity of shaking is measured on the modified **Mercalli scale**. The shallower an earthquake, the more damage to structures it causes.

At the Earth's surface, earthquakes manifest themselves by shaking and sometimes displacement of the ground. When the epicenter of a large earthquake is located offshore, the sea-bed may be displaced sufficiently to cause a tsunami. Earthquakes can also trigger landslides, and occasionally volcanic activity.

In its most general sense, the word "*earthquake"* is used to describe any seismic event — whether natural or caused by humans — that generates seismic waves. Earthquakes are caused mostly by rupture of geological faults, but also by other events such as volcanic activity, landslides, mine blasts, and nuclear tests. An earthquake's point of initial rupture is called its **focus** or "**hypocenter"**. The "**epicenter"** is the point at ground level directly above the hypocenter.

5.6.2.1 Size and frequency of occurrence of earthquakes

It is estimated that around 5,00,000 earthquakes occur each year, detectable with current very sensitive instruments. About 1,00,000 of these can be felt. Minor earthquakes occur nearly constantly around the world. The number of seismic stations has increased from about 350 in 1931 to many thousands today. As a result, many more earthquakes are reported than in the past, but this is because of the vast improvement in instrumentation, rather than an increase in the number of earthquakes. The United States Geological Survey estimates that, since 1900, there have been an average of 18 major earthquakes (magnitude 7.0–7.9) and one great earthquake (magnitude 8.0 or greater) per year, and that this average has been relatively stable. In recent years, the number of major earthquakes per year has decreased.

Most of the world's earthquakes (90%, and 81% of the largest) take place in the 40,000 km long, horseshoe-shaped zone called the circum-Pacific seismic belt, known as the Pacific Ring of Fire, which for the most part bounds the Pacific Plate. Massive earthquakes tend to occur along other plate boundaries, too, such as along the Himalayan Mountains.

With the rapid growth of mega-cities such as Mexico City, Tokyo and Tehran, in areas of high seismic risk, some seismologists are warning that a single quake may claim the lives of up to 3 million people.

5.6.2.2 Measuring and locating earthquakes

Earthquakes can be recorded by seismometers up to great distances, because seismic waves travel through the whole Earth's interior. The absolute magnitude of a quake is conventionally reported by numbers on the moment magnitude scale (formerly **Richter scale**, magnitude 7 causing serious damage over large areas), whereas the felt magnitude is reported using the modified **Mercalli intensity scale**.

Every tremor produces different types of seismic waves, which travel through rock with different velocities:

- Longitudinal P-waves
- Transverse S-waves
- Surface waves

Propagation velocity of the seismic waves ranges from 3 km/s up to 13 km/s, depending on the density and elasticity of the medium. In the Earth's interior the shock or P waves travel much faster than the S waves (approx. relation 1.7 : 1). The differences in travel time from the epicentre to the observatory are a measure of the distance and can be used to image both sources of quakes and structures within the Earth. Also the depth of the hypocenter can be computed roughly.

In solid rock P-waves travel at about 6 to 7 km per second; the velocity increases within the deep mantle to ~13 km/s. The velocity of S-waves ranges from 2–3 km/s in light sediments and 4–5 km/s in the Earth's crust up to 7 km/s in the deep mantle. As a consequence, the first waves of a distant earthquake arrive at an observatory via the Earth's mantle.

Earthquakes are not only categorized by their magnitude but also by the place where they occur. The world is divided into 754 **Flinn–Engdahl regions** (**F-E regions**), which are based on political and geographical boundaries as well as seismic activity. More active zones are divided into smaller F-E regions whereas less active zones belong to larger F-E regions.

5.2.3.1 **Effects of earthquakes**

5.**6.2.3.1 Shaking and ground rupture**

Shaking and ground rupture are the main effects created by earthquakes, principally resulting in more or less severe damage to buildings and other rigid structures. The severity of the local effects depends on the complex combination of the earthquake magnitude, the distance from the epicenter, and the local geological and geomorphological conditions, which may amplify or reduce wave propagation. The ground-shaking is measured by ground acceleration.

Ground rupture is a visible breaking and displacement of the Earth's surface along the trace of the fault, which may be of the order of several metres in the case of major earthquakes. Ground rupture is a major risk for large engineering structures such as dams, bridges and nuclear power stations and requires careful mapping of existing faults to identify any which are likely to break the ground surface within the life of the structure.

5.6.2.3.2 Landslides and avalanches

Earthquakes, along with severe storms, volcanic activity, coastal wave attack, and wildfires, can produce slope instability leading to landslides, a major geological hazard. Landslide danger may persist while emergency personnel are attempting rescue.

5.**6.2.3.3Fires**

Earthquakes can cause fires by damaging electrical power or gas lines. In the event of water mains rupturing and a loss of pressure, it may also become difficult to stop the spread of a fire once it has started. For example, more deaths in the earthquake were caused by fire than by the earthquake itself.

5.**6.2.3.4 Soil liquefaction**

Soil liquefaction occurs when, because of the shaking, water-saturated granular material (such as sand) temporarily loses its strength and transforms from a solid to a liquid. Soil liquefaction may cause rigid structures, like buildings and bridges, to tilt or sink into the liquefied deposits. For example, in the 1964 Alaska earthquake, soil liquefaction caused many buildings to sink into the ground, eventually collapsing upon themselves.

5.6.2.3.5 Tsunami

Tsunamis are long-wavelength, long-period sea waves produced by the sudden or abrupt movement of large volumes of water. In the open ocean the distance between wave crests can surpass 100 kilometers, and the wave periods can vary from five minutes to one hour. Such tsunamis travel 600-800 kilometers per hour, depending on water depth. Large waves produced by an earthquake or a submarine landslide can overrun nearby coastal areas in a matter of minutes. Tsunamis can also travel thousands of kilometers across open ocean and wreak destruction on far shores hours after the earthquake that generated them.

Ordinarily, earthquakes under magnitude 7.5 on the Richter scale do not cause tsunamis, although some instances of this have been recorded. Most destructive tsunamis are caused by earthquakes of magnitude 7.5 or more.

5.6.2.3.6 Floods

A flood is an overflow of any amount of water that reaches land. Floods occur usually when the volume of water within a body of water, such as a river or lake, exceeds the total capacity of the formation, and as a result some of the water flows or sits outside of the normal perimeter of the body. However, floods may be secondary effects of earthquakes, if dams are damaged. Earthquakes may cause landslips to dam rivers, which collapse and cause floods.

5.6.2.3.7 Human impacts

An earthquake may cause injury and loss of life, road and bridge damage, general property damage, and collapse or destabilization (potentially leading to future collapse) of buildings. The aftermath may bring disease, lack of basic necessities, and higher insurance premiums.

5.6.3 TSUNAMI

A **tsunami** is a word which in Japanese means "harbour wave"; this is also known as a **seismic sea wave** or **tidal wave.** It is a series of waves in a body of water caused by the displacement of a large volume of water, generally in an ocean or a large lake. Earthquakes, volcanic eruptions and other underwater explosions (including detonations of underwater nuclear devices), landslides, glacier calving, meteorite impacts and other disturbances above or below water all have the potential to generate a tsunami. In being generated by the displacement of water, a tsunami contrasts both with a normal ocean wave generated by wind and with tides, which are generated by the gravitational pull of the Moon and the Sun on bodies of water.

Tsunami waves do not resemble normal sea waves, because their wavelength is far longer. Rather than appearing as a breaking wave, a tsunami may instead initially resemble a rapidly rising tide, and for this reason they are often referred to as ***tidal waves***. Tsunamis generally consist of a series of waves with periods ranging from minutes to hours, arriving in a so-called "wave train". Wave heights of tens of metres can be generated by large events. Although the impact of tsunamis is limited to coastal areas, their destructive power can be enormous and they can affect entire ocean basins; the 2004 Indian Ocean tsunami was among the deadliest natural disasters in human history with at least 2,30,000 people killed or missing in 14 countries bordering the Indian Ocean.

5.6.3.1 History of Tsunami

As early as 426 BC the Greek historian Thucydides inquired in his book *History of the Peloponnesian War* about the causes of tsunami, and was the first to argue that ocean earthquakes must be the cause.

The Roman historian Ammianus Marcellinus described the typical sequence of a tsunami, including an incipient earthquake, the sudden retreat of the sea and a following gigantic wave, after the 365 AD tsunami devastated Alexandria.

While Japan may have the longest recorded history of tsunamis, the sheer destruction caused by the 2004 Indian Ocean earthquake and tsunami event mark it as the most devastating of its kind in modern times, killing around 2,30,000 people. The Sumatran region is not unused to tsunamis either, with earthquakes of varying magnitudes regularly occurring off the coast of the island.

Tsunamis are an often underestimated hazard in the Mediterranean Sea region and Europe in general. Of historical and current importance are: the 1755 Lisbon earthquake and tsunami (which was caused by the Azores–Gibraltar Transform Fault), the1783 Calabrian earthquakes, each causing several ten thousand deaths and the 1908 Messina earthquake and tsunami. The latter took more than 1,23,000 lives in Sicily and Calabria and is among the most deadly natural disasters in modern Europe.

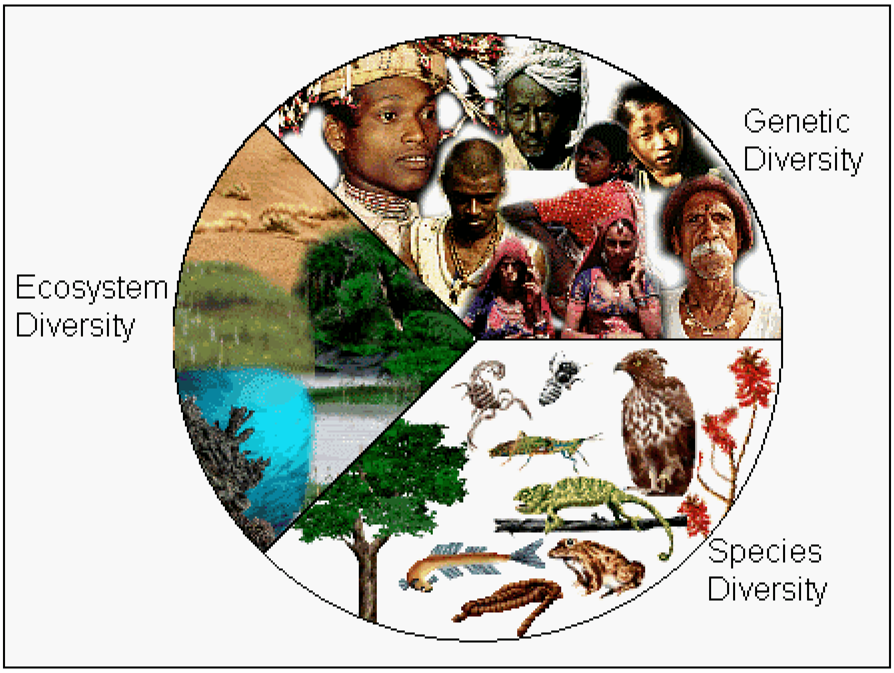
5.6.3.2 Generation mechanisms

The principal generation mechanism (or cause) of a tsunami is the displacement of a substantial volume of water or perturbation of the sea. As discussed above the displacement of water can be because of earthquakes, landslides, volcanic eruptions, glacier calvings or more rarely by meteorites and nuclear tests. The waves formed in this way are then sustained by gravity. Tides do not play any part in the generation of tsunamis.

5.7 Biodiversity

The term biodiversity was coined by Walter G. Rosen in the year 1985. The term has been defined variously by various scientists. A precise definition as given by IUCN (UNEP, 1992) states that, “Biodiversity is the totality of genes, species, and ecosystem in a region”. According to Technology Assessment office of USA, biological diversity is the variety and variability among living organisms and the ecological complexes in which they occur. The biological diversity concept can be divided at three levels – The Genetic Diversity, The

Species Diversity, and The Ecosystem diversity – as shown in the following figure:



The Genetic Diversity: At this level of organization, the diversity includes the variation within species.

The Species Diversity: This level of biodiversity includes full range of species within a specified area and includes viruses, bacteria, plants and animals.

The Ecosystem diversity: On this scale the biodiversity includes variations in the biological communities.

5.7.1 Functions of Biodiversity

Two main functions of biodiversity are:

1. It is the source on which the entire human species depends on for food, fibre, shelter, fuel and medicine.
2. It depends on biosphere which in turn leads to stability in climate, water, soil, air and overall health of biosphere.

5.7.2 Value of Biodiversity

Definition and estimation of the value of biodiversity is not easy. The value of biodiversity is classified into:

1. **Direct Value and**
2. **Indirect Value**

7.2.1 Direct value of biodiversity is of two types

1. Consumptive use value and
2. Productive use value

5.7.2.1.1Consumptive use value: The consumptive use value is the value placed on nature's products that are consumed directly, without passing through a market. Some of them are firewood, food, and game meat. Consumptive value seldom appears in national income accounts, but could be easily included in measures such as GDP. It is valued from the cost if resource was sold at market value, rather than being consumed.

High consumptive use values on resources may lead to the following problems:

1. Over-exploitation of wildlife in developing countries
2. Loss of traditional controls on hunting and
3. Loss of wildlife populations at productive levels.

Consumptive use value benefits the communities closest to the resource if harvested sustainably and managed efficiently.

5.7.2.1.2 Productive use value: Productive use value refers to products that are commercially harvested (sold in a market). Its value is estimated at the production end rather than retail end by adding an inflated cost to the finished product. Productive use value is often the only value of biological resource reflected in national income accounts and may have a major impact on the national economy. Timber, fish, honey, construction materials, mushrooms, fruits, medicinal plants and game meat sold in a market have productive use value.

5. 7.2.2 Indirect value of biodiversity

Indirect values provide economic benefits without being harvested and do not appear in GDP. However, they are crucial to other natural products which influence the GDP. These values involve functions performed by biodiversity which are not of any use *e.g.* Ecological Processes etc. Direct values are often derived from indirect values because plants and animals are supported by the services provided by their environments. Many classes of plant and animal species are consumed by tribal and non-tribal communities. Some examples of indirect values are:

1. Ecological functions
2. Flood and storm protection
3. Waste assimilation
4. Microclimatic functions
5. Nutrient cycles
6. Photosynthesis
7. Carbon stores
8. Soil protection, etc.

Indirect value of biodiversity is of the following types:

1. Non-consumptive use value
2. Optional value
3. Existence or ethical value and
4. Information value

5.7.2.2.1 Non-consumptive use value: This indirect value deals with nature's functions and services. It includes photosynthesis of plants which provides support system for other species by maintaining water cycle, regulating climate, production and protection of the soil, absorption and breakdown of pollutants, recreational, aesthetic, socio-cultural, scientific, educational, spiritual and historic values of natural environments. Recreational value is important with regard to tourism and helps the national GDP.

5.7.2.2.2 Optional value: This refers to the potential of biodiversity that is currently known and needs to be explored. This refers to the idea that there may be several existing species that may prove to be important in future and their usefulness needs to be studied with reference to a specific problem currently plaguing the society. *e.g.*:

1. The growing biotechnology field is searching for the cure for diseases like cancer and AIDS.
2. Medicinal plants and herbs play a very important role in the economic growth of our country.

5.7.2.2.3 Existence value: This is the value gained from continuous knowledge of existence. Also, this is the value that people are willing to pay to keep a species/community/ecosystem from going extinct. Examples of this are high amounts being spent for animals like pandas, whales, lions etc. Our rich heritage teaches us to worship plants, animals, rivers and mountains. Examples being the Ganga river, trees like Banyan and Peepal and plants like the Vambu, Tulsi and Vengai are worshipped.

5.7.2.2.4 Information value: This relates to the educational, scientific, aesthetic and tourism values of biodiversity in an ecosystem

5. 7.2.2.5 Aesthetic Values: Beautiful plants and animals inspire us to protect biodiversity. The most important aesthetic value of biodiversity is eco-tourism.

1. People from distant places spend time and money to visit areas where they can enjoy aesthetic value of biodiversity. This is called eco-tourism.
2. The pleasant music of wild birds, beautifully colored butterflies, color of peacocks and color of flowers are very important for their aesthetic value.

5.7.3 Threats to Biodiversity

Any disturbance in a natural ecosystem tends to reduce its biodiversity. Waste generated due to increase in human population and industrialization spoils the environment and leads to decreased diversity in biological species. Any change in the system leads to a major imbalance and threatens the normal ecological cycle. Causes for loss of biodiversity are:

1. Habitat loss
2. Poaching of wildlife and
3. Man-wildlife conflicts

5.7.3.1 Habitat loss:

The loss of populations of interbreeding organisms is caused by habitat loss. Factors influencing habitat loss are:

1. **Deforestation:** Loss of habitat is mainly caused by deforestation activities. Forests and grasslands are cleared for conversion into agriculture lands or settlement areas or developmental projects. Forests and grasslands are natural home to thousands of species which disintegrate due to loss of their natural habitat.
2. **Destruction of wetlands:** Wetlands, estuaries and mangroves are destroyed due to farming, filling and pollution that cause loss of biodiversity.

3. **Habitat fragmentation:** When the habitat is divided into small and scattered patches the phenomenon is called habitat fragmentation. This leads to the disappearance of most wildlife.
4. **Raw material:** To produce hybrid seeds, wild plants are used as raw materials leading to extinction of many wild plant species.
5. **Production of drugs:** Pharmaceutical companies collect wild plants for the production of drugs leading to extinction of several medicinal plant species.
6. **Illegal trade:** Illegal trade of wildlife reduces biodiversity leading to extinction of species.
7. **Developmental activities:** Construction of dams in forest areas coupled with the discharge of industrial effluents kills birds and other aquatic animals.

5.7.3.2 Poaching of wildlife:

Poaching refers to killing animals or commercial hunting. It contributes to loss of biodiversity. Poaching can be of two types:

1. **Subsistence poaching:** This refers to killing animals for survival.
2. **Commercial poaching:** This refers to hunting animals in order to sell their products.

Factors influencing poaching

1. **Human population**: Increased human population in India has led to pressure on forest resources, leading to degradation of wildlife habitats
2. **Commercial activities**: Although a ban has been imposed internationally on the trade of products of endangered species, there is a continued smuggling of wildlife products. Since trading of such products is highly profitable, poachers continue to hunt endangered animals and smuggle their fur, skin and tusks to other countries.

Wildlife products include furs, horns, tusks, live specimens and herbal products.

Richest source of biodiversity lies in developing nations in Asia, Africa and Latin America.

Advanced countries like Europe, North America, Japan, Taiwan, Hong Kong are the major importers of wildlife products.

5.7.4 Conservation of Biodiversity

The following measures should be taken to conserve biodiversity

1. Illegal hunting and trade of animals and animal products should be stopped immediately.
2. People should boycott purchasing coats, purse or bags made of animal skin.
3. Biodiversity laws should be strengthened and culprits should be punished.
4. Adequate crop and cattle compensation schemes must be started.
5. Solar powered fencing must be provided with electric current proof trenches to prevent animals from entering fields.
6. Cropping pattern should be changed near the forest borders.
7. Adequate food and water should be made available for wild animals within forest zones.
8. Development and construction work in and around forest region must be stopped.

Biodiversity is one of the important tools for sustainable development. The commercial, medical, genetic, aesthetic, and ecological importance of biodiversity emphasizes the need for its conservation.

5.7.5 Factors Affecting Biodiversity

1. Biodiversity is disturbed by human activity.
2. Poaching of animals, over-exploitation of natural sources and degradation of habitats affect biodiversity.
3. Marine ecosystems are disturbed due to oil spills and discharge of effluents.
4. Climatic factors like global warming, ozone depletion and acid rain also affect biodiversity.

5.7.6 Need for Biodiversity

1. It provides recreation and tourism.
2. Drugs, herbs, food and other important raw materials are derived from plants and animals.
3. It preserves the genetic diversity of plants and animals.

4. It ensures sustainable utilization of life supporting systems on earth.
5. It needs to conservation of essential ecological diversity and life supporting systems.
6. Loss of biodiversity leads to ecological and environmental deterioration.

5.7.7 Biodiversity Conservation

There are two types of biodiversity conservation:

1. *In-situ* conservation and
2. *Ex-situ* conservation

5.7.7.1 IN-SITU CONSERVATION

In-situ conservation involves protection of flora and fauna within its natural habitat. The natural habitats or ecosystems under *in-situ* conservation are called "protected areas".

1. Biosphere reserves
2. National parks
3. Wildlife sanctuaries
4. Gene sanctuaries

Biosphere reserves cover large areas (>5000 sq.km.). They are normally used to protect species for a long time. The roles of biosphere reserves are listed below:

1. Long-term survival of evolving ecosystem.
2. Protect endangered species.
3. Protect maximum number of species and communities.
4. Serve as site of recreation and tourism.
5. May also be used for educational and research purposes.

Biosphere reserves function as an open system and changes in land use are not allowed. No tourism and explosive activities are allowed in biosphere reserves.

A **national park** is an area dedicated for the conservation of wildlife along with its environment. It covers an area ranging from 100 to 500 sq.km. One or more national parks may exist within a biosphere reserve. A national park is used for enjoyment through tourism, without affecting the environment. It is used to protect, propagate and develop wildlife. Grazing domestic animals inside national parks is prohibited. All private rights and forestry activities are prohibited inside a national park

Wildlife sanctuary is an area that is reserved for the conservation of animals only.

1. It protects animals only.
2. It allows operations such as harvesting of timber, collection of forest products, private ownership rights and forestry operations, provided it does not affect animals adversely.

Gene sanctuary is an area where plants are conserved. Main purpose of gene sanctuaries is to conserve genetic diversity in natural habitats. India has setup its first gene sanctuary in the Garo Hills of Assam for wild relatives of citrus. Efforts are also being made to setup gene sanctuaries for banana, sugarcane, rice and Mango.

Other projects for the conservation of animals are Project Tiger, Gir Lion Project, Crocodile breeding project, project elephant *etc.*

Advantages of *in-situ* conservation

1. It is cheap and convenient
2. Species get adjusted to natural disasters like drought, floods, forest fires etc.

Disadvantages of *in-situ* conservation

1. A large surface area of earth is required to preserve biodiversity.
2. Maintenance is not proper due to shortage of staff and pollution.

5.*7.7.2 Ex-Situ* Conservation

Ex-situ conservation involves protection of flora and fauna outside their natural habitats. This type of conservation is mainly done for conservation of crop varieties and wild relatives of crops.

1. *Ex-situ* conservation involves maintenance and breeding of endangered plant and animal species under controlled conditions.
2. It identifies those species that are at a high risk of extinction.
3. It prefers species that are important for man in the near future among the endangered species.

5.7.7.2.1 Important centers of *ex-situ* conservation:

1. Botanical gardens

2. Seed banks
3. Microbial culture collections
4. Tissue and cell cultures
5. Museums and
6. Zoological gardens

5.7.7.2.2 Methods of *ex-situ* conservation: Government of India has established certain centers for the conservation of its plant and animal resources. These are:

National Bureau of Plant Genetic Resources (NBPGR): It is located in New Delhi and uses the Cryopreservation Technique to preserve agricultural and horticultural crops. Cryopreservation technique involves using liquid nitrogen at -196^{o}C. Varieties of rice, turnip, radish, tomato, onion, carrot, chilli, tobacco have been successfully preserved for years using this technique.

National Bureau of Animal Genetic Resources (NBAGR): It is located in Karnal, Haryana and preserves the semen and cell line of various livestock animals.

National Facility for Plant Tissue Culture Repository (NFPTCR): In this facility, conservation of varieties of crop plants or trees is done using tissue culture. This facility has been created within the NPBGR.

5.7.7.2.3 Advantages of Ex-situ conservation

1. Physiology of animal is monitored for better reproduction.
2. Survival of endangered species increases due to special care and attention.
3. In captive breeding the animals are assured of medical facility, food, water, shelter and security thereby have a longer life span.
4. It is carried-out in cases of endangered species that do not have any chance of survival in the wild.

5.7.7.2.4 Disadvantages of *Ex-situ* conservation

1. It is an expensive method.
2. Freedom of wildlife is lost.
3. Animals reared in captivity usually cannot survive in the natural environment.

5.7.8 Biodiversity Act

Government of India, considering the consistent and persistent loss of biodiversity came forward with Biodiversity Act, 2002. Main aim of the act are to regulate access to genetic resources and associated sharing arrangements, apart from developing policies and programs on long term conservation and protection of biological resources and associated knowledge. The National Biodiversity Authority (NBA) was set up at Chennai on 1st October 2003 as per the provisions of the Biological Diversity Act, 2002 is mandated to facilitate implementation of the Act. Notable Points of the act are: 1) All foreign national require approval from NBA for obtaining Biological Resources, 2) Indian individuals/entities to seek approval before transferring knowledge/research and material to foreigners, 3) Prior approval of NBA before applying for any kind of IPR based on research conducted on biological material and or associated knowledge obtained from India, 4) Indians required to provide prior intimation to State Biodiversity Boards for obtaining biological material for commercial purposes. SBB can regulate such access, 5) Growers and cultivators of Biological Diversity and vaids and hakims who are practicing Indian system of medicines and local people exempted. Salient features of the Biodiversity Act, 2002 are:

- 1. Biodiversity Management Committees [The Biodiversity Act, 2002 (2)] – It defines the duties of The Central and The State Governments, State Biodiversity Board, Functions and Powers of The National Biodiversity Authority, Regulation of Access to Biological Diversity, Definitions, Introduction, Contents.
- 2. References [The Biodiversity Act, 2002 (3)] It is about Conclusion, Nagoya Protocol, Significance/ Role in Pharmaceutical Industry, Forms etc.
- 3. The Biological Diversity Act 2002 was born out of India's attempt to realize the objectives enshrined in the United Nations Convention on Biological Diversity (CBD) 1992, which recognizes the sovereign rights of states to use their own Biological Resources. Developed countries use the biogenetic resources accessed from the developing countries. It results in beginning of the unprotected flow of genetic information from the developing countries to the capital-rich west, and a protected flow in the reverse direction mainly through patents and Plant Breeders' Rights (PBR)

- 4. [The Biodiversity Act, 2002 (5)] It is about conservation of biological diversity, sustainable use of its components and fair and equitable sharing of the benefits arising out of the use of biological resources and knowledge.
- 5. "Biological resources" mean plants, animals and micro-organisms or parts thereof, their genetic material and by-products (excluding value added products) with actual or potential use or value, but does not include human genetic material;
- 6. "Commercial utilization" means end uses of biological resources for commercial utilization such as drugs, industrial enzymes, food flavors, fragrance, cosmetics, emulsifiers, oleoresins, colors, extracts and genes used for improving crops and livestock through genetic intervention, but does not include conventional breeding or traditional practices in use in any agriculture, horticulture, poultry, dairy farming, animal husbandry or bee keeping [The Biodiversity Act, 2002 (7)].
- 7. "Sustainable use" means the use of components of biological diversity in such manner and at such rate that does not lead to the decline of the biological diversity thereby maintaining its potential to meet the needs and aspirations of present and future generations [The Biodiversity Act, 2002 (8)].
- 8. Regulation of Access to Biological Diversity: No person shall, without previous approval of the National Biodiversity Authority, obtain any biological resource occurring in India or knowledge associated there to for research or for commercial utilization or for bio-survey and bio-utilization [The Biodiversity Act, 2002 (9)].
- 9. The persons who shall be required to take the approval of the National Biodiversity Authority under sub-section (1) are the following, namely :-(a) a person who is not a citizen of India; (b) a citizen of India; who is a non-resident as defined in clause (30) of section 243 of 1961 of the Income-tax Act, 1961; (c) a body corporate, association or organization (i) not incorporated or registered in India; or (ii) incorporated or registered in India under any law for the time being in force which has any non-Indian participation in its share capital or management [The Biodiversity Act, 2002 (10)].
- 10. No person shall apply for any intellectual property right, by whatever name called, in or outside India for any invention based on any

research or information on a biological resource obtained from India without obtaining the previous approval of the National Biodiversity Authority [The Biodiversity Act, 2002 (11)].

- 11. Provided further that the National Biodiversity shall dispose of the application for permission made to it within a period of ninety days from the date of receipt thereof. Process for approval: 1) Application shall be made in form III for getting approval with fee of 500. 2) Authority investigate the application and if satisfy approval shall be granted as a written agreement [The Biodiversity Act, 2002 (12)].
- 12. The head office of the national biodiversity authority shall be at Chennai. There will be Chairperson, Members ex-officio (10), non-official (5) [The Biodiversity Act, 2002 (13)].
- 13. The Central Government may remove any member from NBA who has – adjudged offence of an immoral act, physically or mentally abusing its position, incapable financial or other interest [The Biodiversity Act, 2002 (16)].
- 14. Functions and powers of the national biodiversity authority Sec. 18 (1). It shall be the duty of the National Biodiversity Authority to regulate activities, and (2) grant approval for undertaking any activity referred to in section 3, 4 and 6. (3) The National Biodiversity Authority may – (a) advise the Central Government on matters relating to the conservation of biodiversity, sustainable use of its components and equitable sharing of benefits arising out of the utilization of biological resources. (b) advise the State Governments in the selection of areas of biodiversity importance as heritage sites and take measures for the management of such heritage sites. (4) The National Biodiversity Authority may, on behalf of the Central Government, take any measures necessary to oppose the grant of intellectual property rights in any country outside India on any biological resource obtained from India or knowledge associated with such biological resource which is derived from India [The Biodiversity Act, 2002 (18)].
- 15. State biodiversity board Sec. 22 (1). With effect from such dates as the State Government may appoint, for the purposes of this Act, a Board for the State to be known as the ________________(name of the State) Biodiversity Board. The Board shall consist of the following members, namely:- a) a Chairperson, b) five ex-officio members, c) five members

from among the experts in matters relating to conservation of biological diversity, sustainable use of biological resources and equitable sharing of benefits arising out of the use of biological resources [The Biodiversity Act, 2002 (19)].

- 16. The functions of the State Biodiversity Board shall be to – (a) advise the State Government, on matters relating to the conservation of biodiversity, sustainable use of its components and equitable sharing of the benefits arising out of the utilization of biological resources; (b) regulate by granting of approvals or otherwise requests for commercial utilization or bio-survey and bio-utilization of any biological resource by Indians [The Biodiversity Act, 2002 (20)].
- 17. Procedure for third party transfer of accessed biological resource: Person shall make an application to the Authority in Form IV, accompanied by a fee of ten thousand rupees in the form of Bank draft or cheque drawn in favor of the Authority. The Authority shall after collecting any additional information, decide upon the application as far as possible within a period of six months of receipt of the same. The approval as may be granted in the form of a written agreement decided by the Authority [The Biodiversity Act, 2002 (21)].
- 18. Duties of the central and the state governments: To develop national strategies, plans, etc., for conservation of biological diversity:- (1) The Central Govt. provides in-situ and ex-situ conservation of biological resources, (2) To provide immediate measures for safety of biological areas rich in biological diversity, (3) The Central Govt. shall integrate the conservation, promotion and sustainable use of biological diversity and provide measures for protection [The Biodiversity Act, 2002 (22)].
- 19. Powers of Central Govt. to designate Repositories: (1) Designate institutions as repositories for different categories of biological resources, (2) To keep safe custody of the biological material including voucher specimens, (3) To keep safe custody of any new taxon discovered by any person [The Biodiversity Act, 2002 (23)].
- 20. Chronicling of knowledge relating to biological diversity. The Biodiversity Act, 2002 (24) is about conservation of land races, folk varieties and cultivars, domesticated stocks and breeds of animals and micro organisms, sustainable use and documentation of biological diversity including preservation of habitats, promoting conservation.

- 21. (a) “Cultivar” means a variety of plant that has originated and persisted under cultivation or was specifically bread for the purpose of cultivation, (b) “folk variety” means a cultivated variety of plant that was developed, grown and exchanged informally among farmers, (c) “landrace” means primitive cultivar that was grown by ancient farmers and their successors [The Biodiversity Act, 2002 (25)].
- 22. Application form (Form I) for access to Biological resources and associated traditional knowledge, Application for seeking prior approval of National Biodiversity Authority for transferring the results of research to foreign nationals, companies, NRIs, for commercial purposes (Form II), for seeking prior approval of National Biodiversity Authority for applying for Intellectual Property Right (Form III), form for seeking approval of National Biodiversity Authority for third party transfer of the accessed Biological resources and associated traditional knowledge (Form IV), memorandum of Appeal Within 30-45 days (Form V), notice for hearing of the appeal (Form VI) must be submitted before NBA [The Biodiversity Act, 2002 (26)].
- 23. Significance/Role in Pharmaceutical Industry: The NBA deals with the requests for access to bio-resources and associated traditional knowledge by foreign nationals, institutions or companies, and all matters pertaining to the transfer of research findings to any foreign national, imposition of terms and conditions to secure equitable sharing of benefits, establish sovereign rights over the bio-resources of India and approval for seeking any form of Intellectual Property Rights (IPRs) in or outside India for an invention based on research or information pertaining to a biological resource [The Biodiversity Act, 2002 (27)].
- 24. The Act imposes certain restrictions on request made by industries related to access to biological resources and traditional knowledge if the request is on: a) endangered taxa, b) endemic and rare taxa, c) likely to have adverse effects on the livelihood of the local people and adverse and irrecoverable environmental impacts, d) cause genetic erosion or affect ecosystem function [The Biodiversity Act, 2002 (28)].
- 25. Establishing more predictable conditions for access to genetic resources and implementation of Nagoya Protocol (The Nagoya Protocol is a supplementary agreement to the Convention on Biological Diversity). To access genetic resources and the fair and equitable

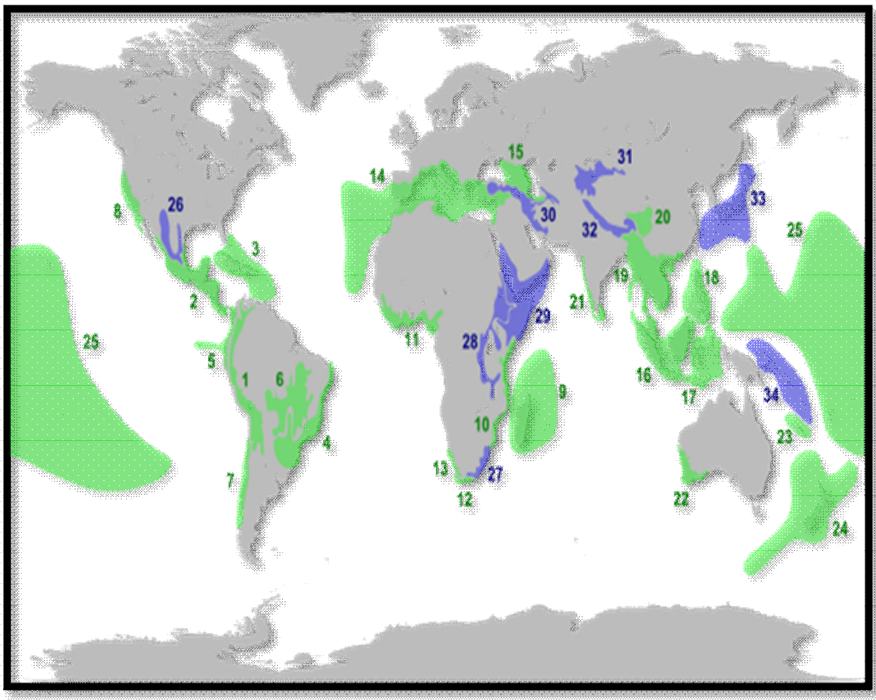
sharing of benefits arising from their utilization to the Convention on Biological Diversity. The Nagoya Protocol will create greater legal certainty and transparency for both providers and users of genetic resources [The Biodiversity Act, 2002 (29)].

- 26. Access obligations:- Domestic-level access measures are to: a) Create legal certainty, clarity and transparency, b) Provide fair and non-arbitrary rules and procedures, c) Establish clear rules and procedures for prior informed consent and mutually agreed terms, d) Provide for issuance of a permit or equivalent when access is granted, e) Create conditions to promote and encourage research contributing to biodiversity conservation and sustainable use [The Biodiversity Act, 2002 (30)].
- 27. a) Pay due regard to cases of present or imminent emergencies that threaten human, animal or plant health, b) Consider the importance of genetic resources for food and agriculture for food security Benefit-sharing obligations:- Domestic-level benefit-sharing measures are to provide for the fair and equitable sharing of benefits arising from the utilization of genetic resources with the contracting party providing genetic resources [The Biodiversity Act, 2002 (31)].

5.7.8.1 Biodiversity hotspot

A **biodiversity hotspot** is a biogeographic region with a significant reservoir of biodiversity that is under threat from humans. Norman Myers wrote about the concept in two articles "Hotspots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions".

To qualify as a biodiversity hotspot on Myers 2000 edition of the hotspot-map, a region must meet two strict criteria: it must contain at least 0.5% or 1,500 species of vascular plants as endemics, and it has to have lost at least 70% of its primary vegetation. Around the world, 34 areas qualify under this definition, with nine other 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.



South Asia: In South Asia four hotspots have been recognized, which are as follows:

- Eastern Himalaya, Nepal
- Indo-Burma, India and Myanmar
- Western Ghats, India
- Sri Lanka, Sri Lanka

Out of these four two are found in India and adjoining countries. These are western Ghats and the Indo-Myanmar border.

Hotspot conservation initiatives

Only a small percentage of the total land area within biodiversity hotspots is now protected. Several international organizations are working in many ways to conserve biodiversity hotspots.

- **Critical Ecosystem Partnership Fund** (CEPF) is a global program that provides funding and technical assistance to nongovernmental organizations and participation to protect the Earth's richest regions of plant and animal diversity including: biodiversity hotspots, high-biodiversity wilderness areas and important marine regions. It works in more than 40 countries on four continents, with headquarters near Washington, D.C.

- The **World Wildlife Fund** has derived a system called the "Global 200 Ecoregions", the aim of which is to select priority Ecoregions for conservation within each of 14 terrestrial, 3 freshwater, and 4 marine habitat types. They are chosen for their species richness, endemism, taxonomic uniqueness, unusual ecological or evolutionary phenomena, and global rarity. All biodiversity hotspots contain at least one Global 200 Ecoregion.
- **Birdlife International** has identified 218 "Endemic Bird Areas" (EBAs) each of which hold two or more bird species found nowhere else. Birdlife International has identified more than 11,000 Important Bird Areas all over the world.
- **Plantlife International** coordinates several organizations all over the world aiming to identify Important Plant Areas.
- **Alliance for Zero Extinction** is an initiative of a large number of scientific organizations and conservation groups who co-operate to focus on the most threatened endemic species of the world. They have identified 595 sites, including a large number of Birdlife's **Important Bird Areas**.
- The **National Geographic Society** has prepared a world map of the hotspots and Arc View shape file and metadata for the Biodiversity Hotspots including details of the individual endangered fauna in each hotspot, which is available with Conservation International.

5.7.9 Biodiversity hotspots of India

5.7.9.1 The Western Ghats

The Western Ghats are a chain of hills that run along the western edge of peninsular India. Because of their proximity to the ocean, they receive high rainfall. These regions have moist deciduous forest and rain forest. The region shows high species diversity as well as high levels of endemism. Nearly 77% of the amphibians and 62% of the reptile species found here are found nowhere else. The region shows biogeographical affinities to the Malayan region, and the Satpura hypothesis proposed by Sunder Lal Hora suggests that the hill chains of Central India may have once formed a connection with the forests of northeastern India and into the Indo-Malayan region. Hora used torrent stream fishes to support the theory, but it was also suggested to hold for birds. Later studies have suggested that Hora's original model species were a demonstration of convergent evolution rather than speciation by isolation.

More recent phylogeographic studies have attempted to study the problem using molecular approaches. There are also differences in taxa which are dependent on time of divergence and geological history. Along with Sri Lanka this region also shows some fauna similarities with the Madagascan region especially in reptiles and amphibians. Examples include the *Sinophis* snakes, the purple frog and Sri Lankan lizard *Nessia,* which appears similar to the Madagascan genus *Acontias*. Numerous floral links to the Madagascan region also exist. An alternate hypothesis that these taxa may have originally evolved out-of-India has also been suggested.

Bio-geographical quirks exist with some taxa of Malayan origin occurring in Sri Lanka but absent in the Western Ghats.

5.7.9.2 The Eastern Himalayas

The Eastern Himalayas is the region encompassing Bhutan, northeastern India, and southern, central, and eastern Nepal. The region is geologically young and shows high altitudinal variation. It has nearly 163 globally threatened species including the one-horned rhinoceros (*Rhinoceros unicornis*), the Wild Asian water buffalo (*Bubalus bubalis*) and in all 45 mammals, 50 birds, 17 reptiles, 12 amphibians, 3 invertebrate and 36 plant species. The relict dragonfly (*Epiophlebia laidlawi*) is an endangered species found here with the only other species in the genus being found in Japan. The region is also home to the Himalayan newt (*Tylototriton verrucosus*), the only salamander species found within Indian limits.

5.7.10 Kaziranga National Park

Kaziranga National Park is a national park in the Golaghat and Nagaon districts of the state of Assam, India. A World Heritage Site, the park hosts two-thirds of the world's great one-horned rhinoceroses. Kaziranga boasts the highest density of tigers among protected areas in the world and was declared a Tiger Reserve in 2006. The park is home to large breeding populations of elephants, wild water buffalo, and swamp deer. Kaziranga is recognized as an **Important Bird Area** by Birdlife International for conservation of avifaunal species. Compared to other protected areas in India, Kaziranga has achieved notable success in wildlife conservation. Located on the edge of the Eastern Himalaya biodiversity hotspot, the park combines high species diversity and visibility.

Kaziranga is a vast expanse of tall elephant grass, marshland, and dense tropical moist broadleaf forests, crisscrossed by four major rivers, including the Brahmaputra, and the park includes numerous small bodies of water. Kaziranga has been the theme of several books, songs, and documentaries. The park celebrated its centennial in 2005 after its establishment in 1905 as a reserve forest.

The history of Kaziranga as a protected area can be traced back to 1904, when Mary Curzon, Baroness Curzon of Kedleston, the wife of the Viceroy of India, Lord Curzon of Kedleston, visited the area. After failing to see a single rhinoceros, for which the area was renowned, she persuaded her husband to take urgent measures to protect the dwindling species which he did by initiating planning for their protection. On 1 June 1905, the Kaziranga Proposed Reserve Forest was created with an area of 232 km^2.

Over the next three years, the park area was extended by 152 km^2, to the banks of the Brahmaputra River. In 1908, Kaziranga was designated a **Reserve Forest**. In 1916, it was redesignated as a game sanctuary—***The Kaziranga Game Sanctuary***—and remained so till 1938, when hunting was prohibited and visitors were permitted to enter the park.

The Kaziranga Game Sanctuary was renamed the Kaziranga Wildlife Sanctuary in 1950 by P. D. Stracey, the forest conservationist, in order to rid the name of hunting connotations. In 1954, the government of Assam passed the **Assam (Rhinoceros) Bill**, which imposed heavy penalties for rhinoceros poaching. Fourteen years later, in 1968, the state government passed the Assam National Park Act of 1968, declaring Kaziranga a designated national park. The 430 km^2 park was given official status by the central government on 11 February 1974. In 1985, Kaziranga was declared a World Heritage Site by UNESCO for its unique natural environment.

Kaziranga has been the target of several natural and man-made calamities in recent decades. Floods caused by the overflow of the river Brahmaputra, lead to significant losses of animal life. Encroachment by people along the periphery has also led to a diminished forest cover and loss of habitat. An ongoing separatist movement in Assam led by the United Liberation Front of Asom (ULFA) has crippled the economy of the region, but Kaziranga has remained unaffected by the movement; a commendable instance of rebels from the United Liberation Front of Assam protecting the animals and, in extreme cases, killing poachers, have been reported since the 1980s.

Kaziranga is located between latitudes 26°30' N and 26°45'N, and longitudes 93°08' E to 93°36'E within two districts in the Indian state of Assam—the Kaliabor subdivision of Nagaon district and the Bokakhat subdivision of Golaghat district. The park is approximately 40 km in length from east to west, and 13 km in breadth from north to south. Kaziranga covers an area of 378 km^2, with approximately 51.14 km^2 lost to erosion in recent years. A total addition of 429 km^2 along the present boundary of the park has been made and designated with separate national park status to provide extended habitat for increasing the population of wildlife or, as a corridor for safe movement of animals to Karbi Anglong Hills. Elevation ranges from 40 m to 80 m. The park area is circumscribed by the Brahmaputra River, which forms the northern and eastern boundaries, and the Mora Diphlu forms the southern boundary. Other notable rivers within the park are the Diphlu and Mora Dhansiri.

Kaziranga has flat expanses of fertile, alluvial soil, formed by erosion and silt deposition by the River Brahmaputra. The landscape consists of exposed sandbars, riverine flood-formed lakes known as, *beels*, (which make up 5% of the surface area), and elevated regions known as, *chapories*, which provide retreats and shelter for animals during floods. Many artificial *chapories* have been built with the help of the Indian Army to ensure the safety of the animals. Kaziranga is one of the largest tracts of protected land in the sub-Himalayan belt, and due to the presence of highly diverse and visible species, has been described as a *"biodiversity hotspot"*. The park is located in the Indomalaya ecozone, and the dominant biomes of the region are Brahmaputra Valley, semi-evergreen forests of the tropical and subtropical moist broadleaf forests biome and a frequently flooded variant of the Terai-Duar savanna and grasslands of the tropical and subtropical grasslands, savannas, and shrublands biome.

The park experiences three seasons: summer, monsoon, and winter. The winter season, between November and February, is mild and dry, with a mean high of 25°C (77 °F) and low of 5 °C (41 °F). During this season, all water channels dry up. The summer season between March and May is hot, with temperatures reaching a high of 37 °C. During this season, animals usually are found near water bodies. The rainy monsoon season lasts from June to September, and is responsible for most of Kaziranga's annual rainfall of 2,220 mm. During the peak months of July and August, three-fourths of the western region of the park is submerged, due to the rising water level of the Brahmaputra. The flooding causes most animals to migrate to elevated and forested regions outside the southern border of the park, such as the Mikir hills. 540 animals, including 13 rhinos and mostly hog deers perished in unprecedented floods of 2012. However, occasional dry spells create problems as well, such as food shortages and occasional forest fires.

Kaziranga contains significant breeding populations of 35 mammalian species, of which 15 are threatened as per the IUCN Red List. The park has the distinction of being home to the world's largest population of the Greater One-Horned Rhinoceros (1,855), wild Asiatic water buffalo (1,666) and eastern swamp deer (468). Significant populations of large herbivores include elephants (1,940), gaur (30) and sambar (58). Small herbivores include the Indian muntjac, wild boar, and hog deer. Kaziranga has the largest population of the Wild water buffalo anywhere accounting for about 57% of the world population.

Kaziranga is one of the few wild breeding areas outside Africa for multiple species of large cats, such as Indian tigers and leopards. Kaziranga was declared a Tiger Reserve in 2006 and has the highest density of tigers in the world (one per five km^2), with a population of 118, according to the latest census. Other felids include the jungle cat, fishing cat, and leopard cat. Small mammals include the rare hispid hare, Indian gray mongoose, small Indian mongooses, large Indian civet, small Indian civets, Bengal fox, golden jackal, sloth bear, Chinese pangolin, Indian pangolins, hog badger, Chinese ferret badgers, and particoloured flying squirrel. Nine of the 14 primate species found in India occur in the park. Prominent among them are the Assamese macaque, capped and golden langur, as well as the only ape found in India, the hoolock gibbon. Kaziranga's rivers are also home to the endangered Gangetic dolphin.

Kaziranga has been identified by Birdlife International as an Important Bird Area. It is home to a variety of migratory birds, water birds, predators, scavengers, and game birds. Birds such as the lesser white-fronted goose, ferruginous duck, Baer's pochard duck, lesser adjutant, greater adjutant, black-necked stork, and Asian openbill stork migrate from Central Asia to the park during winter. Riverine birds include the Blyth's kingfisher, white-bellied heron, Dalmatian pelican, spot-billed pelican, Nordmann's greenshank, and black-bellied tern. Birds of prey include the rare eastern imperial, greater spotted, white-tailed eagle, Pallas's fish eagle, grey-headed fish eagle, and the lesser kestrel.

Kaziranga was once home to seven species of vultures, but the vulture population reached near extinction, supposedly by feeding on animal carcasses containing the **drug Diclofenac**. Only the Indian vulture, slender-billed vulture, and Indian white-rumped vulture have survived. Game birds include the swamp francolin, Bengal florican, and pale-capped pigeon. Other families of birds inhabiting Kaziranga include the great Indian hornbill and wreathed hornbill, Old World babblers such as Jerdon's and marsh babblers, weaver birds such as the common baya weaver, threatened Finn's weavers, thrushes such as Hodgson's bushchat and Old World warblers such as the bristled grassbird. Other threatened species include the black-breasted parrotbill and the rufous-vented prinia.

Two of the largest snakes in the world, the reticulated python and rock python, as well as the longest venomous snake in the world, the king cobra, inhabit the park. Other snakes found here include the Indian cobra, Russell's viper, and the common krait. Monitor lizard species found in the park include the Bengal monitor and the water monitor. Other reptiles include fifteen species of turtle, such as the endemic Assam roofed turtle and one species of tortoise, the brown tortoise. 42 species of fish are found in the area, including the *Tetraodon*.

Four main types of vegetation exist in this park. These are alluvial inundated grasslands, alluvial savanna woodlands, tropical moist mixed deciduous forests, and tropical semi-evergreen forests. Based on Landsat data for 1986, percent coverage by vegetation is: tall grasses 41%, short grasses 11%, open jungle 29%, swamps 4%, rivers and water bodies 8%, and sand 6%.

There is a difference in altitude between the eastern and western areas of the park, with the western side being at a lower altitude. The western reaches of the park are dominated by grasslands. Tall elephant grass is found on higher ground, while short grasses cover the lower grounds surrounding the *beels* or flood-created ponds. Annual flooding, grazing by herbivores, and controlled burning maintain and fertilize the grasslands and reeds. Common tall grasses are sugarcanes, spear grass, elephant grass, and the common reed. Numerous forbs are present along with the grasses. Amidst the grasses, providing cover and shade are scattered trees—dominant species including kumbhi, Indian gooseberry, the cotton tree (in savanna woodlands), and elephant apple (in inundated grasslands). Thick evergreen forests, near the Kanchanjhuri, Panbari, and Tamulipathar blocks, contain trees such as *Aphanamixis polystachya, Talauma hodgsonii, Dillenia indica, Garcinia tinctoria, Ficus rumphii, Cinnamomum bejolghota*, and species of *Syzygium*. Tropical semi-evergreen forests are present near Baguri, Bimali, and Haldibari. Common trees and shrubs are *Albizia procera, Duabanga grandiflora, Lagerstroemia speciosa, Crateva unilocularis, Sterculia urens, Grewia serrulata, Mallotus philippensis, Bridelia retusa, Aphania rubra, Leea indica,* and *Leea umbraculifera*.

There are many different aquatic floras in the lakes and ponds, and along the river shores. The invasive water hyacinth is very common, often choking the water bodies, but it is cleared during destructive floods. Another invasive species, *Mimosa invisa*, which is toxic to herbivores, was cleared by Kaziranga staff with help from the Wildlife Trust of India in 2005.

Kaziranga National Park has been granted maximum protection under the Indian law for wildlife conservation. Various laws, which range in dates from the Assam Forest Regulation of 1891 and the Biodiversity Conservation Act of 2002 have been enacted for protection of wildlife in the park. Poaching activities, particularly of the rhinoceroses for its horn, has been a major concern for the authorities. Between 1980 and 2005, 567 rhinoceroses were hunted by poachers. Following a decreasing trend for the past few years, 18 one-horned rhinoceroses were killed by poachers in 2007. Reports have suggested that there are links between these poaching activities and funding of terrorism Organization. But these could not be substantiated in later years. Preventive measures such as construction of anti-poaching camps and maintenance of existing ones, patrolling, intelligence gathering, and control over the use of firearms around the park have reduced the number of casualties. Since 2013, the park used cameras on drones which are monitored by security guards to protect the rhino from armed poachers.

Perennial flooding and heavy rains have resulted in death of wild animals and damage to the conservation infrastructures. To escape the water-logged areas, many animals migrate to elevated regions outside the park boundaries where they are susceptible to hunting, hit by speeding vehicles, or subject to reprisals by villagers for damaging their crops. To mitigate the losses, the authorities have increased patrols, purchased additional speedboats for patrol, and created artificial highlands for shelter. Several corridors have been set up for the safe passage of animals across National Highway–37, which skirts around the southern boundary of the park. To prevent the spread of diseases and to maintain the genetic distinctness of the wild species, systematic steps such as immunization of livestock in surrounding villages and fencing of sensitive areas of the park, which are susceptible to encroachment by local cattle, are undertaken periodically.

Water pollution due to run-off from pesticides from tea gardens, and run-off from a petroleum refinery at Numaligarh, pose a hazard to the ecology of the region. Invasive species such as Mimosa and wild rose have posed a threat to the native plants in the region. To control the growth and irradiation of invasive species, research on biological methods for controlling weeds, manual uprooting and weeding before seed settling are carried out at regular intervals. Grassland management techniques, such as controlled burning, are affected annually to avoid forest fires.

5.8 Summary

This chapter includes Major terrestrial biomes,Theory of island biogeography,Bio-geographical zones of India,Environmental pollution – air, water, noise and radiation (electromagnetic and ionizing),Global environmental changes – El Nino and La Nina,Natural Disasters – Earthquakes and Tsunami.

The Biodiversity part incudes – status, monitoring and documentation, major drivers of biodiversity change; biodiversity management approaches; Outline knowledge of Biodiversity Act of India. Biodiversity hotspots in India- Western ghats and north East (ecology and major fauna); UNESCO heritage sites (special mention of Kaziranga National Park).

5.9 Glossary

- **Alpine:** Part of mountain above tree line, but below permanent snow.
- **Altitude:** Height above sea level.
- **Anthropogenic emission:** Emissions of green house gases, green house gas precursors, and aerosols associated with human activities.
- **Arid Zone:** A zone of very low rainfall.
- **Atmosphere:** The gaseous envelope surrounding a planet.
- **Bioaccumulation:** An increase in the concentration of a chemical in specific organs or tissues at a level higher than would normally be expected.
- **Biodegradation:** Oxidative breakdown of synthetic or natural organic substances by microbial activity.

- **Biodiversity:** Refers to the variety and variability among living organisms and the ecological complexes in which they occur. Biological diversity is at three levels: genetic diversity, species diversity and ecosystem diversity.
- **Biome:** A major ecological community of organisms (a complex of several communities may be under different succession stages) maintained under a particular climate zone with a distinct vegetation type. It includes desert, grasslands and forests.
- **Biosphere:** The planet earth along with its living organisms and atmosphere which sustains life *i.e.* the earth and atmosphere in which organism live.
- **Biosphere reserve:** Protected land, water and/or coastal environments with their living organisms that together constitute a world-wide network of scientific information and include significant example of natural biomass and/or unique representative biological area throughout the world.
- **Climate:** Long-term weather condition and factors peculiar to a given environment segment/area due to its geographical situation.
- **Deforestation:** Destruction of forest cover and the undergrowth.
- **Ecological balance:** Maintenance of equilibrium between living components of any ecosystem, so that it remains in stable conditions.
- **Environment:** The sum of all physical, chemical, biotic, and cultural factors that affects life of organism in any way.
- **Environment science:** Interdisciplinary study that uses information from the biological, physical and social science to learn how we interact with the earth, and how to deal with environment problems.
- **Fauna:** Species content of animals present in any area.
- **Flora:** Species content of plants present in any area.
- **Forest:** A biome in which dominant plants are trees.
- **Genetic diversity:** Variability in the genetic makeup among individuals within a single species.
- **Glaciers:** A slowly moving mass of snow and ice which occurs in high mountain region or Polar regions.
- **Grassland:** Herbaceous vegetation dominated by grasses.

- **Green house gases (GHGs):** Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic generated, that absorb and emits radiations at specific wavelength within the spectrum of infrared radiation emitted by the earth's surface, the atmosphere and clouds. This property causes the green house effect. Six gases have been listed as GHGs in Kyoto Protocol – carbon dioxide, nitrous oxide, methane, hydroflurocarbons, perflurocarbons and sulfur hexachloride. Moreover, there are number of entirely human made green house gases in the atmosphere such as the halocarbons and other chlorine and bromine containing substance, dealt with under the Montreal Protocol.
- **Marsh:** Water logged ground with large quantity of minerals.
- **National Parks:** Relatively large land or water areas which contain representative samples and sites of major natural regions, features, scenery, and/or plant and animal species of national or international significance and are of special scientific, educational and recreational interest. They contain one or several entire ecosystem that is not materially altered by human exploitation or occupation. National park are protected and managed by the government in a natural or near natural state. Visitors enter under special conditions for inspirational, educational, cultural and recreational purposes.
- **Ozone hole:** Thinning or break in ozone layer in the stratosphere. Designation of amount of such depletion as "Ozone hole" is made when detected amount of depletion exceeds fifty percent. Seasonal ozone hole have been observed under both the Antarctic region and part of Canada and the extreme Northeastern United States.
- **Ozone layer:** A layer of atmosphere (above 30-50Km from earth surface) which contains ozone produced by UV radiations.
- **Sanctuary:** An area, usually in natural condition which is reserved or set aside by a governmental or private agency for protection of natural fauna or particular species of animals.
- **Smog:** A term applied to fog heavily polluted by smoke, such as used to occur in London, particularly under condition of temperature inversion in winter. The term is also applied to the Lachrymatory haze (such as occurs over Los Angeles) produced by photochemical reactions that occur under the influence of strong sunlight in air polluted by

automobiles exhausted gases under temperature inversion condition. The latter type of smog is usually referred to as photochemical smog or oxidant smog. The irritating, visible haze resulting from the sun's effect on certain pollutants in the air (photo-chemical) and particularly those pollutants from transportation (exhaust) and industry. Also, a mixture of fog, smoke and gaseous waste. It is smoke arising from nitrogen oxides and hydrocarbon emitted by motor vehicles and photochemical action of sunlight.

- **Steppe:** The amount of inorganic substance present at any given time in the environment of an ecosystem.
- **Toxicology:** Study of the harmful effects of toxic substance on living organisms in any ecosystem.
- **Vegetation:** The collective and continuous growth of plant in species *i.e.* totality of plant growth or sum total of plant population covering a region. It is descried, where as flora and fauna are listed.
- **Wetland:** An area that is saturated by surface or ground water having life adapted under those conditions. Swamps, bogs, fens, marshes and estuaries are examples of wetland. These are a major refuge for wildlife including many rare species.
- **Wildlife:** Includes any animal and aquatic and land vegetation, which form part of any habitat. In practice it is used for a particular animal species.
- **Zoogeography**: The study of the geographical distributions of animal.

5.10 Self-Learning Exercise

Section -A (Very Short Answer Type):

1. What are biomes?
2. Who coined the term Island Biogeography?
3. Any unfavourable alteration of our surroundings is known as……
4. …..is the unit of measurement of Noise Pollution.
5. What is El Nino?
6. Name two types of Disasters.
7. What are two important ways of biodiversity conservation?
8. What does IUCN stand for?

Section -B (Short Answer Type) :

1. Define the Desert biome. What are the adaptations found among animals of the biome?
2. What are the major factors that influence species abundance on an Island?
3. What are applications of Island biogeography in conservation biology?
4. What are major sources of Air Pollution?
5. What are effects of Noise pollution on Humans?
6. What are major effects of El Nino?
7. Discuss various effects of Earthquakes.
8. What measure can help us in conservation of Biodiversity?

Section -C (Long Answer Type)

1. What are major terrestrial biomes of the World? Discuss important plant and animal life found in them.
2. What is biogeography? Describe various biogeographic regions of India.
3. What is pollution? Discuss various types of pollution and their effects.
4. Define Biodiversity. What are various values of Biodiversity? Describe important threats to Biodiversity.
5. Write an account of El Nino and La Nina and their impact on global climate?

Answer Key of Section-A

1. Biomes are very large areas on earth's surface with flora and fauna adapted for that particular environment
2. Robert H. MacArthur and E. O. Wilson
3. Pollution
4. Decibel (dB)
5. The periodic warming in the Pacific near South America, often noticed around Christmas, is known as El Nino.
6. Natural and Man-made
7. *In-situ* conservation and*Ex-situ* conservation
8. International Union for Conservation of Nature and natural resources

5.11 References

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Unit - 6

Conservation Biology

Structure of the Unit

6.1 Objectives

After going through this unit you will be able to understand

- Universal Interaction of Conservation with bio-diversity
- Major conservation strategy to management bio-diversity
- Conservation Methodology to manage bio-diversity
- Indian Wildlife Acts and Schedules
- Major Organizations working to manage bio-diversity
- Ramsar Convention with special mention of Sunderbans

6.2 Conservation of Biology

A wide variety of living organisms including plants, animals, and micro-organisms on planet earth makes the world a beautiful place. The huge diversity of living organisms form an inseparable and significant part of our planet, however, though increasing human population is posing serious threats to bio-diversity. There has been a direct loss of species during the development activities; the new environment is unsuitable for the many species to survive. Over-exploitation of recourses reduces the size of the population of a species and may push it towards extinction one day. We can conclude that"Conservation biology is the study of nature and biodiversity with the aim of protecting species, their habitats, and ecosystems from excessive rates of extinction and the erosion of biotic interactions". The Conservation biology and the concept of biodiversity emerged together which helps to emphasize the modern era of conservation science and policies. The major objectives of Conservation biology is protection, upliftment and scientific management of biodiversity so as to maintain it at its threshold level and derive maximum sustainable benefits for the present and future generation on this planet.

Mainly the conservation of biodiversity has three basic Principles as-

(a) To maintain essential ecological processes and life supporting systems.

(b) To preserve the diversity of species.

(c) To make sustainable utilisation of species and ecosystems.

6.3 Major conservation strategy to management:

Conservation is the planned management of natural resources, to retain the balance in nature and retain the diversity. It also includes wise use of natural resources in such a way that the needs of the present generation are met and at the same time leaving enough for the future generations. The following strategies should be undertaken in order to conserve biodiversity:

- All the possible varieties may be old or new of food, forage and timber plants, live stock, agriculture animals and microbes should be conserved.
- Critical habitats for each species should be identified and safeguarded.
- Priority should be given to preserving unique ecosystems.
- There should be the sustainable utilisation of resources.
- International trade in wild life should be highly regulated.
- The poaching and hunting of wildlife should be prevented as far as practicable.
- Care should be taken for the development of reserves and protected areas.
- Efforts should be made to reduce the level of pollutants in the environment.
- Public awareness should be created regarding biodiversity and its importance for the living organisms.
- Priority should be given in wildlife conservation programme to endangered species over vulnerable species and to vulnerable species over rare species.
- The habitats of migratory birds should be protected by bilateral and multilateral agreement.
- The over exploitation of useful products of wild life should be prevented.
- The useful animals, plants, and their wild relatives should be protected both in their natural habitat (in-situ) and in zoological-botanical gardens (ex-situ)

- Efforts should be made for setting up of National parks and wild life sanctuaries to safeguard the genetic diversity and their continuing evolution. Environmental laws should be strictly followed.

6.4 Conservation Management:

To protect and manage the biodiversity & to acchive the Conservation efforts, conservation methods can be grouped into the following two categories:

6.4.1. In-situ methods

In-situ conservation includes the protection of plants and animals within their natural habitats or in protected areas. Protected areas are land or seas dedicated to protecting and maintain biodiversity.

6.4.1.1. Protection of habitat

The main strategy for conservation of species is the protection of habitats in representative ecosystems. Currently, India has ninety-six National Parks, five hundred Wildlife Sanctuaries, thirteen Biosphere Reserves, twenty-seven Tiger Reserves and eleven Elephant Reserves covering an area of 15.67 million hectares or 4.7 % of the geographical area of the country. Twenty-one wetlands, thirty mangrove areas, and four coral reef areas have been identified for intensive conservation and management purposes by the Ministry of Environment and Forests, Govt. of India.

6.4.1.2. National parks and sanctuaries

India is unique in the richness and diversity of its vegetation and wildlife. India's national parks and wildlife sanctuaries (including bird sanctuaries) are situated Ladakh in the Himalayas to Southern tip of Tamil Nadu with its rich bio-diversity and heritage. Wildlife sanctuaries in India attract people from all over the world as the rarest of rare species are found here. With 96 national parks and over 500 wildlife sanctuaries, the range and diversity of India's wildlife heritage are unique. Some of the main sanctuaries in India are The Jim Corbett Tiger Reserve- Uttaranchal, Kanha National Park, Madhya Pradesh, Bandhavgarh National Park- Madhya Pradesh, Ranthambhor National Park-Sawai Madhopur, Gir National Park-Sasangir (Gujarat) etc.

Wildlife lovers eager to see magnificent Bird Sanctuary at Bharatpur, Rajasthan as it is the second habitat in the world that is visited by the Siberian Cranes in winter and it provides a vast breeding area for the native water birds, Great Indian bustard is found in the Indian deserts. In western Himalayas, one can see birds like Himalayan monal pheasant, western tragopanm koklass, white crested khalij pheasant, griffon vultures, lammergiers, choughs, ravens. In the Andaman and Nicobar region, about 250 species and subspecies of birds are found, such as rare Narcondum horn bill, Nicobar pigeon, and megapode. While the national parks and sanctuaries in South India, too. For e.g. Madumalai in Tamil Nadu and Bandipur Tiger Reserve and Nagahole National Park in Karnataka. Many National Parks and Sanctuaries have been established to preserve wildlife in their natural environment. Wildlife Conservation Society (WCS) India in association with other NGO partners and tribal people, is making every possible effort to develop new models of wildlife conservation to preserve India's most treasured fauna and to protect the environment. Some of them are given below along with important species found there.

- Kaziranga sanctuary (Assam) – One-horned rhinoceros
- Manas sanctuary (Assam) – Wild buffaloes
- Gir forest (Gujarat) – Lions, chital, sambar, wild bears
- Kelameru bird sanctuary (Andhra Pradesh) – Pelicans and marine birds
- Dachigam sanctuary (Jammu and Kashmir) – Kashmir stags, Himalayan tahr.
- Bandipur sanctuary (Karnataka) – Indian bison, elephants, langurs
- Periyar sanctuary (Kerala) – Elephants, barking deer, sambhar
- Kanha National Park (Madhya Pradesh) – Tiger, leopards, wild dogs
- Simipal National Park (Orissa) – Mangroves, marine turtles lay eggs
- Bharatpur bird sanctuary (Rajasthan) – Ducks, herons
- Corbett National Park (Uttaranchal) –Tigers, barking deer, rhesus monkey.
- Jaladpara sanctuary (West Bengal) – *Rhinoceros*

6.4.1.3. Biosphere Reserves

These are representative parts of natural and cultural landscapes extending over large areas of terrestrial or coastal/marine ecosystems which are internationally recognized within UNESCO's Man and the Biosphere Program Thirteen biodiversity- rich representative ecosystems , largely within the forest land (total area – 53,000 sq. km.), have been designated as Biosphere Reserves in India. The concept of Biosphere Reserves (BR) was launched in 1975 as a part of UNESCO's Man and Biosphere Program, dealing with the conservation of ecosystems and the genetic material they contain. A Biosphere Reserve consists of the core, buffer and transition zones. (a) The core zone is fully protected and natural area of the Biosphere Reserve least disturbed by human activities. It is legally protected ecosystem in which entry is not allowed except with permission for some special purpose. Destructive sampling for scientific investigations is prohibited.

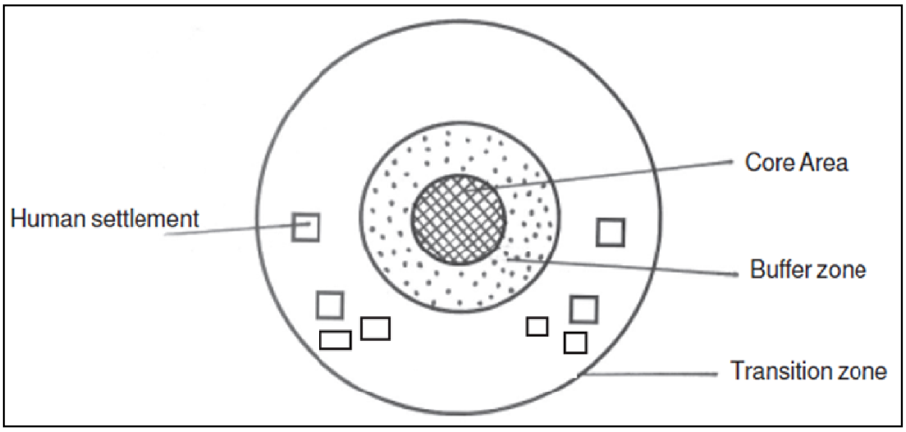

Figure 6.1: Human Settelment (A terrestrial Biosphere reserve).

(b) The buffer zone surrounds the core zone and is managed to accommodate a greater variety of resource use strategies, and research and educational activities. (c) the transition zone, the outermost part of the Biosphere Reserve, is an area of active cooperation between the reserve management and the local people, wherein activities like settlements, cropping, forestry , recreation and other economic that are in harmony with the conservation goals. Till date, there were 553 biosphere reserves located in 107 countries.

The main functions of the biosphere reserves are:

- **Conservation:** Long term conservation of representatives, landscapes and different types of ecosystems, along with all their species and genetic resources.
- **Development:** Encourages traditional resource use and promote economic development which is culturally, socially and ecologically sustainable.
- **Scientific research, monitoring and education-** Support conservation research, monitoring, education and information exchange related to local, national and global environmental and conservation issues.

6.4.1.4. Species-oriented projects

Certain species have been identified as needing a concerted and specifically directed protection effort. Project Tiger, Project Elephant and Project crocodile are examples of focusing on single species through conserving their habitats.

Project Tiger – A success in species conservation: Tigers which were once abundant in Indian forests have been hunted. As a result tiger population within the country declined drastically from estimate of 40,000 at the turn of century to 1200 by the 1970. This led to initiate the Project Tiger in 1973 with the objective of conserving and rescuing this species from extinction. In 2007, there were more than 40 Project Tiger wildlife reserves covering an area of 37,761 km^2. Project Tiger helped to increase the population of these tigers from 1,200 in the 1970s to 3,500 in 1990s. However, a 2008 census held by Government of India revealed that the tiger population had dropped to 1,411. A total ban has been imposed on hunting of tigers and trading in tiger products at the national and international levels. Elaborate management plans are made for each of the tiger reserves for tiger habitat improvement and antipoaching measures.

6.4.1.5. Sacred forests and sacred lakes:

A traditional strategy for the protection of biodiversity has been in practice in India and some other Asian countries in the form of sacred forests. These are small forest patches protected by tribal communities due to religious sanctity. These have been free from all disturbances. Sacred forests are located in several parts of India i.e. Karnataka, Maharashtra, Kerala, Meghalaya. Similarly, several water bodies for example, Khecheopalri Lake in Sikkim, have been declared sacred by the people, leading to protection of aquatic flora and fauna.

6.4.2 Ex-situ Conservation

Ex-situ conservation of plants and animals outside their natural habitats. These include botanical gardens, zoo, gene banks, seek bank, tissue culture and cryopreservation. To complement in-situ conservation efforts, ex-situ conservation is being undertaken through setting up botanic gardens, zoos, medicinal plant parks, etc by various agencies. The strategies for ex-situ conservations are:

- Identification of species to be conserved.
- Adoption of Different ex-situ methods of conservation.
- Long-term captive breeding for the species which have lost their habitats permanently.
- Short-term propagation and release of the animals in their natural habitat
- Animal translocation
- Animal reintroduction
- Advanced technology in the service of endangered species.
- It gives longer life time and breeding activity to animals.

- Genetic techniques can be utilised in the process.
- Captivity breed species can again be reintroduced in the wild.

Some disadvantages of this method are:

(a) The favourable conditions may not be maintained always.

(b) Mew life forms cannot evolve.

(c) This technique involves only few species.

6.4.2.1. Gene Banks

Ex-situ collection and preservation of genetic resources is done through gene banks and seed banks. The National Bureau of Plant Genetic Resources (NBPGR), New Delhi preserves seeds of wild relatives of crop plants as well as cultivated varieties; the National Bureau of Animal Genetic Resources at Karnal, Haryana maintains the genetic material for domesticated animals, and the National Bureau of Fish Genetic Resources, Lucknow for fishes.

6.4.2.2. Cryopreservation

("freeze preservation") is particularly useful for conserving vegetative propagated crops. Cryopreservation is the storage of material at ultra low temperature of liquid nitrogen (-196°C) and essentially involves suspension of all metabolic processes and activities. Cryopreservation has been successfully applied to meristems, zygotic and somatic embryos, pollen, protoplasts cells and suspension cultures of a number of plant species.

6.4.2.3. Conservation at molecular level (DNA level)

In addition to above, germplasm conservation at molecular level is now feasible and attracting attention. Cloned DNA and material having DNA in its native state can all be used for genetic conservation. Furthermore, non-viable material representing valuable genotypes stored in gene banks can all be used as sources of DNA libraries from where a relevant gene or a combination of genes can be recovered.

6.4.2.4. Legal measures

Market demand for some body parts like bones of tiger, rhino horns, furs, ivory, skins, musk, peacock feathers, etc results in killing the wild animals. The Wildlife Protection Act (1972) contains provisions for penalties or punishment to prevent poaching and illegal trade. India is also a signatory to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

6.5 Wildlife Acts and Schedules:

The Wildlife Protection Act, 1972 is an Act of the India enacted for protection of plants and animal species. Before 1972, India only had five designated national parks. Among other reforms, the Act established schedules of protected plant and animal species; hunting or harvesting these species was largely outlawed. The Act provides for the protection of wild animals, birds and plants; and for matters connected therewith or ancillary or incidental thereto. It has six schedules which give varying degrees of protection. Schedule I and part II of Schedule II provide absolute protection - offences under these are prescribed the highest penalties. Species listed in Schedule III and Schedule IV are also protected, but the penalties are much lower. Schedule V includes the animals which may be hunted. The plants in Schedule VI are prohibited from cultivation and planting. The hunting to the Enforcement authorities have the power to compound offences under this Schedule. The Penalties are prescribed in section 51, in which againt victim, the Forest Department, the Police, the Wildlife Crime Control Bureau (WCCB), the Customs and the Central Bureau of Investigation (CBI) can filed Chargesheets directly .

In the another act as Biological Diversity Act, 2002, provides for setting up of a National Biodiversity Authority (NBA), State Biodiversity Boards (SBB) and Biodiversity Management Committees (BMC) in local bodies. The SBB may prohibit the import if found to violate the objectives of conservation, sustainable use and benefit sharing. The monetary benefits, fees and royalties, as a result of approvals by NBA are to be deposited in National Biodiversity Fund which will be used for conservation and development of areas in consultation with local self government. The Wildlife Protection Act (1972) and Biodiversity Act (2002) at the national level and The CITES and The Convention on Biodiversity at the international level regulate the trade in biodiversity and promote its conservation and sustainable use.

6.6 Hot Spots

Hot spots are the areas with high density of biodiversity or mega diversity which are most threatened at present. Biodiversity Hot Spots features are 1.Locations around the world that is characterized by exceptional levels of endemic species and critical levels of habitat loss.

2. At least 1500 species of vascular plants are endemic 3. The region must have lost at least 70 percent of its original habitat. There are 34 hot spots in world,

out of which four are located in India namely(1) Western Ghats (2) North-East Himalaya(3) Indo-Burma Region and (4) Andaman and Nicobar Islands of Sundaland. The hot spots are determined considering four factors:

(i) Degrees of endemism;

(ii) Degree of expectation

(iii) Degrees of threat to habitat due to its degradation and fragmentation and

(iv) Number of Species diversity.

6.7 CITES

The CITES is a Convention on International Trade in Endangered Species of Wild Fauna and Flora that is a multilateral treaty to protect endangered plants and animals. it also known as the Washington Convention that was drafted as a result of a resolution adopted in 1963 at a meeting of members of the International Union for Conservation of Nature (IUCN). Its aim is to ensure the international trade in specimens of wild animals and plants that does not threaten the survival of the species in the wild, and it accords varying degrees of protection to more than 35,000 species of animals and plants.

6.8 The World Wide Fund for Nature (WWF):

It is an international non-governmental organization, working in the field of the biodiversity conservation, and the reduction of humanity's footprint on the environment. It was formerly named the World Wildlife Fund. The group's mission is "to stop the degradation of the planet’s natural environment and to build a future in which humans live in harmony with nature." Among other issues, it is also concerned with endangered species, sustainable production of commodities and climate change. WWF's current strategy for achieving its mission specifically focuses on restoring populations of 36 species (species or species groups that are important for their ecosystem or to people, including elephants, tunas, whales, dolphins and porpoises), and ecological footprint in 6 areas (carbon emissions, cropland, grazing land, fishing, forestry and water). The organization also works on a number of global issues driving biodiversity loss and unsustainable use of natural resources, including finance, business practices, laws, and consumption choices. Local offices also work on national or regional issues.

6.9 Traffic

It is a joint program of World Wide Fund for Nature (WWF) and the World Conservation Union (IUCN). It is a wildlife trade monitoring network that is leading as non-governmental organization working globally on trade in wild animals and plants in the context of both biodiversity conservation and sustainable development. TRAFFIC also works in co-operation with the Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The main objectives are as :

- Investigating and analyzing wildlife trade trends, patterns, impacts and drivers to provide the leading knowledge base on trade in wild animals and plants;
- Informing, supporting and encouraging action by governments, individually and through inter-governmental cooperation to adopt, implement and enforce effective policies and laws;
- Providing information, encouragement and advice to the private sector on effective approaches to ensure that sourcing of wildlife uses sustainability standards and best practice;
- Developing insight into consumer attitudes and purchasing motivation and guiding the design of effective communication interventions aimed to dissuade purchasing of illicit wildlife goods.
- Developing insight into consumer attitudes and purchasing motivation and guiding the design of effective communication interventions aimed to dissuade purchasing of illicit wildlife goods.

6.10 Environmental Information System:

ENVIS is serving the interests of policy formulation and environment management at all levels of Government as well as decision-making aimed at environmental protection and its improvement for sustaining good quality of life of all living beings. The purpose has been to ensure integration of national efforts in web-enabled environmental information collection, collation, storage, retrieval and dissemination to all concerned, including policy planners, decision-makers, researchers, scientists and the public.

The major objectives of the Scheme are as follows:

- To build up a repository and dissemination Centre in environmental science and engineering.

- To gear up state-of-art technologies of information acquisition, processing, storage, retrieval and dissemination of environmental nature.
- To support and promote research, development and innovation in environmental information technology.
- To provide national environmental information service relevant to present needs and capable of meeting the future needs of the users, originators, processors and disseminators of information.
- To build up storage, retrieval and dissemination capabilities, with the ultimate objective of disseminating information speedily to the users.
- To promote national and international cooperation and liaison for exchange of environment-related information.
- To promote, support and assist education and personnel training programmes designed to enhance environmental information processing and utilizing capabilities.
- To promote and exchange of environment-related information amongst developing countries.

6.11 IUCN (International Union for Conservation of Nature and Natural Resources)

The International Union for Conservation of Nature and Natural Resources is an international organization working in the field of nature conservation and sustainable use of natural resources. It is involved in data gathering and analysis, research, field projects, advocacy, lobbying, and education. IUCN's mission is to "influence, encourage and assist societies throughout the world to conserve nature and to ensure that any use of natural resources is equitable and ecologically sustainable." IUCN was established in 1948. It was previously called the International Union for Protection of Nature (1948–1956) and the World Conservation Union (1990–2008). The organization is best known to the wider public for compiling and publishing the IUCN Red List, which assesses the conservation status of species worldwide.

The IUCN Red List of Threatened Species founded in 1964, is the world's most comprehensive inventory of the global conservation status of biological species. The International Union for the Conservation of Nature (IUCN) is the world's main authority on the conservation status of species. A series of Regional Red Lists are produced by countries or organizations, which assess the risk of extinction to species within a political management unit. The IUCN Red List is set upon precise criteria to evaluate the extinction risk of thousands of species and subspecies. According to IUCN (1996), the formally stated goals of the Red List are (1) to provide scientifically based information on the status of species and subspecies at a global level, (2) to draw attention to the magnitude and importance of threatened biodiversity, (3) to influence national and international policy and decision-making, and (4) to provide information to guide actions to conserve biological diversity. Collectively, assessments by these organizations and groups account for nearly half the species on the Red List. These categories are defined below in Table.

Table 6.1: The IUCN Threat Categories

List Category	**Definition**
Extinct	A taxon is extinct when there is no reasonable doubt that the last individual has died.
Extinct in the wild	A taxon is extinct in the wild when exhaustive surveys in known and/or expected habitats have failed to record an individual.
Critically endangered	A taxon is critically endangered when it is facing high risk of extinction in the wild in immediate future.
Endangered	A taxon is endangered when it is not critically endangered but is facing a very high risk of extinction in the wild in near future.
Vulnerable	A taxon is vulnerable when it is not critically endangered or endangered but is facing high risk of extinction in the wild in the medium term future.
Lower risk	A taxon is lower risk when it has been evaluated and does not satisfy the criteria for critically endangered, endangered or vulnerable.
Data deficient	A taxon is data deficient when there is inadequate information to make any direct or indirect assessment of its risk of extinction.

Not evaluated	A taxon is not evaluated when it has not yet been assessed against the above criteria.

The IUCN Red List is an authentic source of information for this purpose. The 2000 Red List is the latest available. It uses a set of criteria, relevant to all species and all regions of the world, to evaluate the extinction risk of species. The 2000 Red List contains an assessment of more than 18,000 species; 11,000 of which are threatened (5,485 animals and 5611 plants). Out of these, 1,939 are listed as critically endangered (925 animals, and 1,014 plants).According to the Red List, in India, 44 plant species are critically endangered., 113 endangered and 87 vulnerable. Amongst animals, 18 are critically endangered, 54 endangered and 143 Vulnerable. A few examples of these plant and animals are given in table:

Table 6.2*:* Examples of threatened species in India

Category	**Plant species**	**Animal species**
Critically endangered	*Berberis nilghiriensis*	*Sus salvanius*, (Pigmy hog)
Endangered	*Bentinckta nicobarica*	*Allurus fulgens* , (Red Panda)
Vulnerable	*Cupressus cashmeriana*	*Antilope cervicapra*, (Black buck)

6.12 Zoological Survey of India

The Zoological Survey of India (ZSI) is a premier Indian organization in zoological research and studies. It was established on 1 July 1916 to promote the survey, exploration and research of the fauna in the region. The activities of the ZSI are coordinated by the Conservation and Survey Division under the Ministry of Environment, Forest and Climate Change, Government of India. The annals of Zoological Survey of India (ZSI) reflect an eventful beginning for the Survey even before its formal birth and growth. The major objectives of the ZSI are as follows:

- Exploring, Surveying, Inventorying and Monitoring of faunal diversity in various states, selected ecosystems and protected areas of India.

- Taxonomic studies of the faunal components collected.
- Status survey of Threatened and Endemic species.
- Preparation of Red Data Book, Fauna of India and Fauna of States.
- Bio-ecological studies on important communities/species.
- Preparation of database for the recorded species of the country.
- Maintenance and Development of National Zoological Collections.
- Training, Capacity Building and Human Resource Development.
- Faunal Identification, Advisory services and Library Services.
- Publication of results including Fauna of India, Fauna of States and Fauna of Conservation Areas.
- GIS and Remote Sensing studies on recorded animal diversity as well as on threatened species.
- Chromosomal Mapping and DNA Barcoding.
- Environmental Impact Studies.
- Maintenance of Musea at Headquarters and Regional Centres.
- Development of ENVIS and CITES Centers.
- Research Fellowship, Associateship and Emeritus Scientists Programme.
- Collaborative research programmes on Biodiversity with other Organizations in India and abroad.

6.13 Ramsar Convention

The Ramsar Convention is an international treaty for the conservation and sustainable use of wetlands. It is also known as the Convention on Wetlands. It is named after the city of Ramsar in Iran, where the Convention was signed in 1971. Every three years, representatives of the Contracting Parties meet as the Conference of the Contracting Parties (COP), the policy-making organ of the Convention which adopts decisions (Resolutions and Recommendations) to administer the work of the Convention and improve the way in which the Parties are able to implement its objectives.

Wetlands are vital for human survival. They are among the world’s most productive environments; cradles of biological diversity that provide the water and productivity upon which countless species of plants and animals depend on for survival. Wetlands are indispensable for the countless benefits or "ecosystem services" that they provide humanity, ranging from freshwater supply, food, and building materials, and biodiversity, to flood control, groundwater recharge, and climate change mitigation. Yet study after study demonstrates that wetland area and quality continue to decline in most regions of the world; 64% of the world's wetlands have disappeared in the last century. As a result, the ecosystem services that wetlands provide to people are compromised. Managing wetlands is a global challenge, and the Convention's 169 Contracting Parties recognize the value of having one international treaty dedicated to a single ecosystem. By setting international standards for wetland conservation and providing a forum for discussing global wetland issues, the Convention enables Contracting Parties to share information on wetlands and address issues together. The Convention uses a broad definition of wetlands. It includes all lakes and rivers, underground aquifers, swamps and marshes, wet grasslands, estuaries, deltas and tidal lats, mangroves and other coastal areas, coral reefs, and all human-made sites such as fish ponds, rice paddies, reservoirs and salt pans. The Convention's mission is "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world". The Ramsar Convention works closely with six other organizations known as International Organization Partners (IOPs). These are mainly

- Birdlife International
- International Union for Conservation of Nature (IUCN)
- International Water Management Institute (IWMI)
- Wetlands International
- WWF International
- Wildfowl & Wetlands Trust (WWT)

In India, The Sundarbans is a natural region comprising southern Bangladesh and a small part in Eastern India that was also designated a Ramsar site on 21 May 1992. It is the largest single block of tidal halophytic mangrove forest in the world. The Sundarbans covers approximately 10,000 square kilometres (3,900 sq mi) most of which is in Bangladeshwith the remainder in India. The Sundarbans is a UNESCO World Heritage Site. This region is densely covered by mangrove forests, and is the largest reserves for theBengal tiger. The Sundarbans National Park is a National Park, Tiger Reserve, and aBiosphere Reserve located in the Sundarbans delta in the Indian state of West Bengal.

The Sundarbans freshwater swamp forests are a tropical moist broadleaf forest ecoregion of Bangladesh. It represents the brackish swamp forests that lie behind the Sundarbans Mangroves, where the salinity is more pronounced. According to Champion and Seth (1968), the freshwater swamp forests are characterised by *Heritiera minor, Xylocarpus molluccensis, Bruguiera conjugata, Sonneratia apetala, Avicennia officinalis*, and *Sonneratia caseolaris*, with *Pandanus tectorius*, *Hibiscus tiliaceus,* and *Nipa fruticans* along the fringing banks. The Sundarbans Mangroves ecoregion on the coast forms the seaward fringe of the delta and is the world's largest mangrove ecosystem, with 20,400 square kilometres (7,900 sq mi) of area covered. The dominant mangrove species Heritiera fomes is locally known as sundri or sundari. Mangrove forests are not home to a great variety of plants. They have a thick canopy, and the undergrowth is mostly seedlings of the mangrove trees. Besides the sundari, other species that make up the forest include *Avicennia spp., Xylocarpus mekongensis, Xylocarpus granatum, Sonneratia apetala, Bruguiera gymnorrhiza, Ceriops decandra, Aegiceras corniculatum, Rhizophora mucronata,* and *Nypa fruticans* palms. Twenty-six of the fifty broad mangrove types found in the world grow well in the Sundarbans. **Presenting Flora:** A total 245 genera and 334 plant species were recorded by David Prain in 1903. While most of the mangroves in other parts of the world are characterised by members of the Rhizophoraceae, Avicenneaceae or Combretaceae, the mangroves of Bangladesh are dominated by the Malvaceae and Euphorbiaceae. There is abundance of dhundul or passur (*Xylocarpus granatum*) and kankra (*Bruguiera gymnorrhiza*) though distribution is discontinuous. Among palms, *Poresia coaractata,Myriostachya wightiana* and golpata (*Nypa fruticans*), and among grasses spear grass (*Imperata cylindrica*) and khagra (*Phragmites karka*) are well distributed. The varieties of the forests that exist in Sundarbans include mangrove scrub, littoral forest, saltwater mixed forest, brackish water mixed forest and swamp forest. **Presenting Fauna:** The Sundarbans provides a unique ecosystem and a rich wildlife habitat. According to the 2015 tiger census, the Sundarbans have about 170 tigers (106 in Bangladesh and 64 in India). There is much more wildlife here than just the endangered Royal Bengal tiger (*Panthera tigris tigris*). The forest also contains leopard (*Panthera pardus fusca*) and several other smaller predators such as the jungle cats (*Felis chaus*), fishing cats (*Prionailurus viverrinus*), and leopard cats (*Prionailurus bengalensis*). Unlike in other habitats, tigers live here and swim among the mangrove islands, where they hunt scarce prey such as thechital deer (*Axis axis*), Indian muntjacs (*Muntiacus muntjak*), wild boars (*Sus scrofa*), and even rhesus macaque (*Macaca mulatta*). It is estimated that there are now 500 Bengal tigers and about 30,000 spotted deer in the area. Some reptiles are predators too, including two species of crocodiles, the saltwater crocodile (*Crocodylus porosus*) and mugger crocodile(*Crocodylus palustris*), as well as the gharial (*Gavialis gangeticus*) and the water monitor lizards (*Varanus salvator*), all of which hunt on both land and water. Sharks and the Gangetic dolphins (*Platanista gangetica*) roam the waterways.

Presenting Avifauna: The forest is also rich in bird life, with 170 species including the endemic brown-winged kingfishers (*Pelargopsis amauroptera*) and the globally threatened lesser adjutants (*Leptoptilos javanicus*) andmasked finfoots (*Heliopais personata*) and birds of prey such as theospreys (*Pandion haliaetus*), white-bellied sea eagles (*Haliaeetus leucogaster*) and grey-headed fish eagles (*Ichthyophaga ichthyaetus*). Some more popular birds found in this region areopen billed storks, black-headed ibis, water hens, coots, pheasant-tailed jacanas, pariah kites, brahminy kites, marsh harriers, swamp partridges, red junglefowls, spotted doves, common mynahs, jungle crows, jungle babblers, cotton teals, herring gulls, Caspian terns,gray herons, brahminy ducks, spot-billed pelicans, great egrets, night herons, common snipes, wood sandpipers, green pigeons, rose-ringed parakeets, paradise flycatchers, cormorants, white-bellied sea eagles, seagulls, common kingfishers, peregrine falcons,woodpeckers, whimbrels, black-tailed godwits, little stints, eastern knots, curlews, golden plovers, pintails, white-eyed pochards andlesser whistling ducks.

Presenting Aqua fauna: Some fish and amphibians found in the Sundarbans are sawfish,butter fish, electric ray, common carp, silver carp, barb, river eels,starfish, king crab, fiddler crab, hermit crab, prawn, shrimps,Gangetic dolphins, skipping frogs, common toads and tree frogs. One particularly interesting fish is the mudskipper, a gobioid that climbs out of the water into mudflats and even climbs trees.

Presenting Endangered and extinct species: The endangered species that live within the Sundarbans and extinct species that used to be include the royal Bengal tigers, estuarine crocodile, northern river terrapins (*Batagur baska*), olive ridley sea turtles, Gangetic dolphin, ground turtles, hawksbill sea turtles and king crabs (horse shoe). Some species such as hog deer (Axis porcinus), water buffalos (*Bubalus bubalis*), barasingha or swamp deer (Cervus duvauceli), Javan rhinoceros (*Rhinoceros sondaicus*), single horned rhinoceros (*Rhinoceros unicornis*) and the mugger crocodiles or marsh crocodiles (*Crocodylus palustris*) started to become extinct in the Sundarbans towards the middle of the 20th century, because of extensive poaching and man hunting by the British. There are several other threatened mammal species, such as the capped langurs (*Semnopithecus pileatus*), smooth-coated otters (*Lutrogale perspicillata*), Oriental small-clawed otters (*Aonyx cinerea*), and great Bengal civets (*Viverra zibetha*).

20.10 Summary

The Conservation concept is a protective, scientific management for biodiversity to maintain it for the present and future generation. The process can be managed via the *Insitu* and *Exsitu* management process for biological diversity in nature.The present study revealed on the standard facts of Conservation with details about some projects and processing organizations and biological acts.

21.11 Glossary

- **Adaptive management:** An experimental approach to management, or "structured learning by doing".
- **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.
- **Biome**: the largest ecological regions distinguishable by characteristic plants and animals. There are six: tundra, conifer, deciduous forest, grassland, tropical, and desert.
- **Biosafety**: The policies and actions taken to manage risks from the intentional introduction of new organisms, including genetically modified organisms, that could adversely affect biodiversity, people or the environment.
- **Biosphere**: taken together, the troposphere, oceans, and land surfaces where things live. Also called the Ecosphere.
- **Conservation**: the preservation and protection of natural and historic resources for the purpose of maintaining their intrinsic values, providing

for their appreciation and recreational enjoyment by the public, and safeguarding the options of future generations.

- **Ecosystem management**: A management philosophy intended to sustain the integrity of ecosystems.
- **Ecosystem**: An interacting system of living and non-living parts such as sunlight, air, water, minerals and nutrients.
- **Endemic Species**: An indigenous species which breeds only within a specified region or locality and is unique to that area.
- **Ex situ conservation**: The conservation of species outside their natural habitat (Convention on Biological Diversity).
- **Exotic Species**: those not native to an ecosystem.
- **Germ Plasm:** the hereditary material in germ cells (e.g., genes).
- **Habitat:** The place or type of area in which an organism naturally occurs.
- **Indigenous species:** A plant or animal species which occurs naturally in New Zealand. A synonym is "native".
- **In-situ conservation:** The conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties (Convention on Biological Diversity).
- **Protected area:** A geographically defined area that is protected primarily for nature conservation purposes or to maintain biodiversity values, using any of a range of legal mechanisms that provide long-term security of either tenure or land use purpose.
- **Protected Natural Area (PNA):** A legally protected area, haracterised by indigenous species or ecosystems or landscape features, in which the principal purpose of management is retention of the natural state. In this Strategy, the term is used synonymously with "protected area".
- **Ramsar Convention:** An international convention to protect internationally important wetlands. It was agreed in 1971 and signed by New Zealand in 1976.
- **Species:** A group of organisms capable of interbreeding freely with each other but not with members of other species.

- **Sustainable use:** The use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations.
- **Wetland:** Wetlands are rich in nutrients, unique in ecosystems, and hospitable to many forms of life, including birds on long flyways.

2.12 Self-Learning Exercise

Section -A (Very Short Answer Type):

1. Conservation is --------------------------------
2. Ramsar Convention was agreed in ---------------------.
3. IUCN is -----------------------------------
4. CITES-----------------------
5. Germ Plasm is --------------------------------
6. Two Insitu conservation method are --------------------------------------

Section -B (Short Answer Type):

1. Define the difference between *Insitu* and *Exsitu* conservation methods.
2. Define the Conservation Biology.
3. A Short note on Ramsar Convention.
4. Explain a key note On Tiger Project.
5. Describe a key note on Biosphere.
6. Explain a key note on *Exsitu* Conservation.

Section -C (Long Answer Type)

1. Define the Conservation System In Biodiversity.
2. Write about IUCN and their threates with appropriate examples.
3. Write on Wildlife Acts and Schedules in India.
4. Write about Ramsar Convention with a example of sunderbans concept in India.

6.13 References

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Unit- 7

Introduction to the Study of Animal Behaviour

Structure of the Unit :

7.0 Objectives

This unit will introduce you to (i) what is ethology (study of animal behaviour) (ii) its brief history(iii) why it is useful to study behaviour of animals. (iv) and who are the pioneer scientists in this field and their work.

7.1 Introduction

Behaviour is everything an animal does. Behaviour includes all gestures, postures, expressions, movements animals make. All vocalization, colour change, emission of light and pheromones. **Ethology** is the systematic scientific study of animals behaviour. A behaviour is performed by organism using its muscular, nervous , hormonal systems.

Scientists who study animal behaviour are called as **Ethologists**, they work in forests, in national parks and in reserves using camera, binocular and stop watch. They Watch animals in their natural habitat. Study wide variety of animals from ants to elephants, from weevil to whales and from protozoa to primate. They deal with visible actions which includes innumerable types of behavioural acts and correlate behaviour with environment or vice-versa. Ethologists let their study animals roam around freely in natural habitat, they watch them from hides, they never kill animals.

7. 2 Historical perspective, aims of behavioural research

Paleolithic art from 40,000 years ago provide indirect evidence that primitive humans observed the behaviour of animals. Cave paintings portray herding animals in groups, animal migration, certain predators hunting in packs, and solitary animals alone. Aristotle ((384 BC – 322 BC) was intrigued by the natural world around him , Aristotle provided the first written records of mutualism between organisms, use of tools by animal and brood parasitism .

Reasons to study Ethology

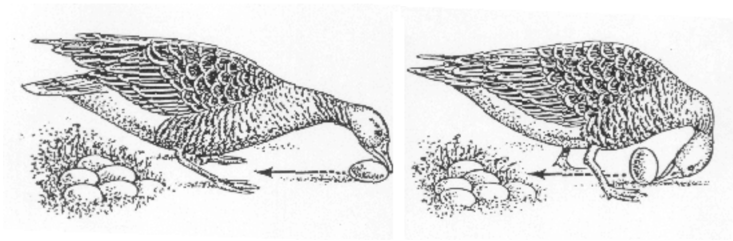
1. To satisfy our Curiosity about animals all around us.
2. To achieve a better understanding of the species we share the Earth with. Our survival dependent on knowledge of other animals .
3. Management of those species we depend for Food and recreation (game species); to control agricultural pests; to maintain ecosystem, we must know to protect endangered species, and our future generation to see them too.
4. Understanding our own behaviour- Studies of how animals make social groups, learn and develop vocalization, and many other behavioural acts provide unique insights into the development and neural control of speech in humans.
5. It has formed an important bridge between the molecular and physiological aspects of biology and ecology ;
6. It has become a link between organisms and environment and between the nervous system and the ecosystem.

7. Behaviour is recognized as one of the most important function of animal life; it plays a critical role in animal adaptations and evolution because through behaviour an organism interacts with its environment.
8. This science has made important contributions to other disciplines like anthropology, sociology, psychology, environment, evolution and sociobiology.
9. Ethology today, has applications to human behaviour, to neurosciences, to the study of animal welfare and to the education of future generations .
10. Basic behavioural studies on reproductive behaviour have led to improved captive breeding methods for near extinction species like whooping cranes, golden lion tamarins, cotton-top tamarins, and many domestic animals.
11. Study of behaviour of animals has benefitted human in many ways. One recent example is the potential to successfully predict earthquakes through the use of toads (Bufo bufo), which were found to detect and respond to a seismic event before it happened (Grant & Halliday 2010).

7.3 Diversity in animal behaviour

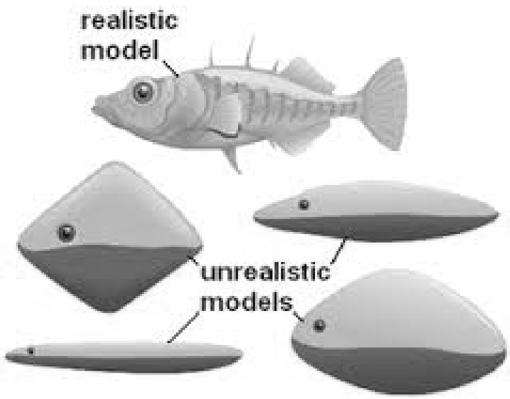
There are two types of behaviour-

(1) **Innate**, also called inherent, inborn, pre programmed, genetically determined called Fixed Action Patterns. They are automatic, developmentally fixed.They are non variable. Despite different environments, all individuals exhibit the same behaviour. Instinctive behavior is something the animal is born knowing how to do. Sexual, nest building, maternal, aggression, eating ,drinking are all innate behaviours. Sequence of behaviors that are essentially unchangeable and conducted to completion once it is started , Triggered by a sign stimulus. EgGraylag goose rolls the egg back to the nest using side-to-side head motions its a classical example given by Konrad Lorenz is designated as Fixed-Action Pattern (FAP). And a **Sign stimulus is a stimulus in the surrounding that triggers the** retrieval process in goose, here it is the site of an egg outside the nest. As the goose sees the egg outside the nest, it gets up and brings the egg back to the nest in a fixed stereotype manner. No matter where these geese are, their behaviour of bringing the egg back to the nest remains same.



In this case sight of an egg outside the nest acts as a sigh stimulus to release retrieval of egg behaviour. Niko Tinbergen was the one who had discovered this phenomenon while studying three spined sticklebacks.

He had observed that during breeding season male fish developed red belly, blue dorsal and green eyes; he constructed a nest of weeds , females did not change colour. He invited females to nest and chased away males. he discovered that it was the red colour of belly that released aggression in territorial male.



A realistic model without red belly was allowed to come closer to nest, whereas, absolutely un realistic models, having red belly were fiercely chased away from territory. It was the red colour which acted as sign stimulus to release aggressive fixed action pattern.

Kinesis and **taxis** are two movement-related fixed behaviours. Kinesis is an increase in random movement and Taxis is movement in a particular direction either toward or away from a stimuli.

(2) **Learned behaviours** - if all behaviours in animals had come fixed, they could not have survived in ever changing surroundings.Therefore, some behaviours are flexible, they can be modified by experience, they are Variable, they can be changed by practice or experience by watching individuals of the same species (conspecifics). You will be studying learning and its various forms in unit 11. It must be clearly understood here that most of the behaviours are completed or performed using both components ie innate and learned.

Mechanisms controlling behaviour:

(i) Genetic mechanisms- Animal behaviour is the result of multiple interacting forces related to an individual's genes, physiology, and development and the internal and external environments in which they live. There is genetic variation among individuals of a population for behaviours related to survival and reproduction. Successful behaviours are passed on to the next generation and may evolve over time. Researchers employ the scientific method and standardized protocols to measure and, thus, understand behaviour. The results of animal behaviour research inform ecology and evolution and assist in solving problems related to conservation. Many organizations and institutions specialize in providing information on animal behaviour and opportunities for professional experiences . Both genes and the environment influence behaviour, and scientists studying behaviour focus on the interaction between these two factors. Genes, via their influences on morphology and physiology, create a framework within which the environment acts to shape the behaviour of an individual animal. The environment can affect morphological and physiological development; in turn behaviour develops as a result of that animal's shape and internal workings.

(ii) Physiological mechanisms- Corticosteroids often become elevated in individuals during stressful conditions. Under these circumstances reproductive and territorial behaviours are suppressed and escape behaviours are promoted .

(iii) Development from embryo to juvenile stages influencesbehaviour in the adult. Resource availability in early development in two species of primates, bonobos (small sized chimpanzee) and chimpanzees , influences whether adults are prone to sharing food . Bonobos live where food is plentiful and do not compete with each other or other species for this resource. They grow up sharing food with other individuals and sharing is maintained into adulthood. On the other hand, chimpanzees compete with each other and gorillas (Gorilla gorilla) for food throughout their lives. Juvenile chimpanzees do not share food with other individuals and adults retain this non-sharing behaviour.

7.4. Scientist and their work

The study of animals behaviour is still in its infancy, nevertheless, considerable research has been done in laboratory and in wild. The major works come from European and American scientists. The classical ethology has its roots in Europe and modern ethology found bearing in USA.

There are many Psychologists, Naturalists and Ethologistswho have contributed significantly in initiating study of animal behaviour. William James (1842 – 1910) , Charles Otis Whitman (1842 – 1910), George Romanes (1848 – 1894) , Ivan P. Pavlov (1849 – 1936) , Sigmund Freud (1856-1939), Thomas Hunt Morgan(1866 – 1945), Oskar Heinroth (1871 – 1945), Edward Thorndike (1874 –1949) , John B. Watson (1878 –1958).

More known scientist are Karl von Frisch (1886 - 1982), KonradLorenz (1903 – 1989) , Skinner (1904 –1990) , Harry Harlow (1905 –1981), Niko Tinbergen (1907 – 1988), Desmond Morris (Born 1928), E.O. Wilson (born 1929) , William D. Hamilton (1936 – 2000) and Richard Dawkins: (born 1941).

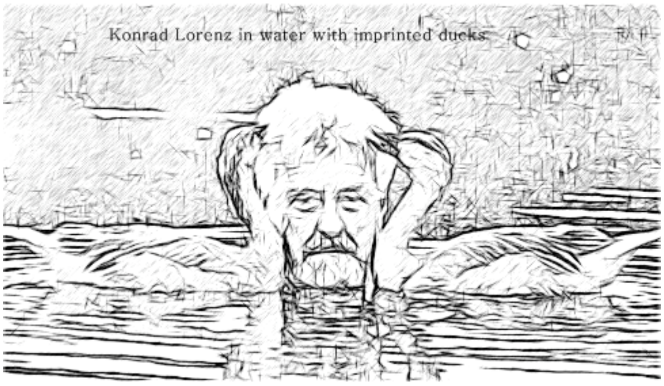
Konrad Lorenz,Niko Tinbergen and Karl Von Frisch jointly won The Nobel Prize in 1973"for their discoveries concerning organization and elicitation of individual and social behaviour patterns" They are called Founders of Ethology.

7.4.1 Konrad Zacharias Lorenz (1903 – 1989) :

He was an Austrian zoologist, ethologist, and ornithologist discovered the phenomenon of early childhood learning called **imprinting**. Young geese form an image of “parent” just after hatching. If the hatchlings first encounter a human, they will imprint on him and follow him around as if he were their mother. Imprinting is irreversible learning limited to a **sensitive period** in an animal's life . Lorenz used the graylag goose and jackdaws to demonstrate imprinting. He took over the maternal role for a group of goslings. When they grew up, they followed Lorenz taking him as conspecific. When these ducks became adults, they courted Lorenz!!Details of this unique phenomenon is described in Unit 11.

He was always interested in animal behaviour, but his father wanted him to be a medical doctor. So He first studied at a medical college. He received an M.D. degree at the University of Vienna in 1928 and later he continued studying animals , and was awarded a Ph.D. in zoology in 1933. He wrote many books-such as "King Solomon's Ring"," On Aggression" and "Man Meets Dog" became popular readings. He received many prestigious awards .From 1961 to 1973 he served as director of the Max Planck Institute for Behaviour Physiology, in Seewiesen, Austria.

Konrad Lorenz was called "Father of Etholgy"by Niko Tinbergen. To honour him a "Konrad Lorenz Institute for Evolution and Cognition Research" is established in Austria, "Konrad Lorenz Institute of Ethology" is in Vienna and Lorenz Institute for Behavioural Physiology in Buldern, Germany.



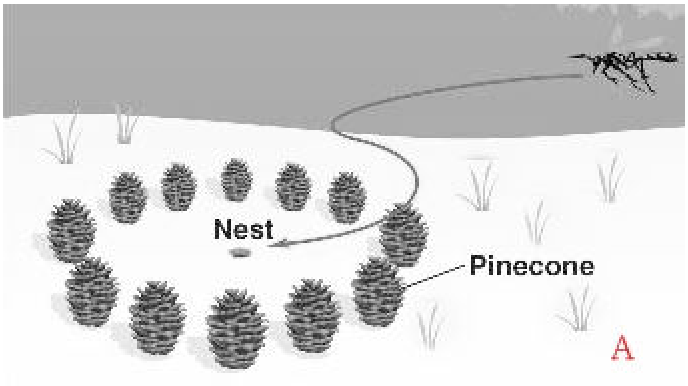
7.4.2 Nikolaas "Niko" Tinbergen (1907 – 1988) :

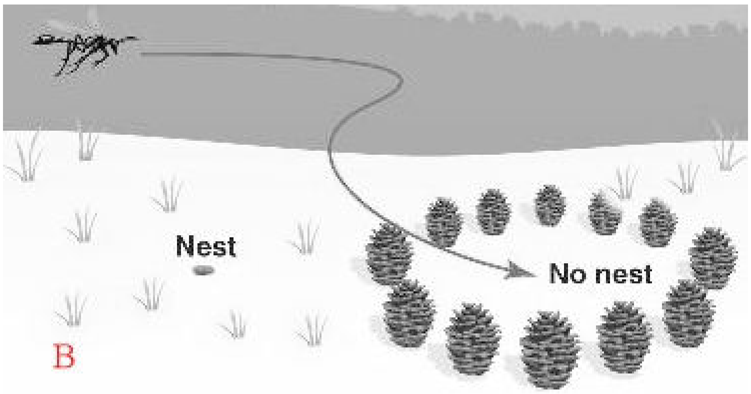
He was a Dutch ethologist and ornithologist who shared the 1973 Nobel Prize in Physiology or Medicine with Karl von Frisch and Konrad Lorenz .

Tinbergen approached animal behaviour studies experimentally in the field, and proposed s “Tinbergen’s four why's.” (which you will be studying in chapter on sociobiology). He proposed the phenomenon of Sign/specific stimulus required to release genetically determined behaviours, his experiments with three spined sticklebacks is considered classic example to support it. His observations on how animals learn is exemplary. Tinbergen wrote about the behaviour of herring gulls, terns, several raptors and owls, about migration and bird territories, and about shells and birds on the beaches, all in many natural history magazines.

He began as a bird-watcher and field-worker with insects in the Netherlands. He established a group of students, many of whom became well known in their field, and brought the science of animal behaviour to a wide public. He was a brilliant communicator as well as a natural field biologist, and gained international recognition with his photography and several behaviour films. In later life he focused his studies on childhood autism.

He is the one who proposed the concept that to release a fixed action pattern a sign stimulus is needed as mentioned earlier. He also conducted a classic experiment with digger wasps to prove that even smallcreatures learn.





situation A : Tinbergen kept pine cones around the nest hole. He noticed that wasp took circling rounds over the nest and flew away.

Situation b : He shifted the pines cones a little away from the nest, when the wasp came, it hovered over pine cones to search its nest! That means in situation A the wasp had learnt that my nest is located between pine cones. This is considered a classic example and is quoted in all text books of animal behaviour.

He was respected very much as an excellent teacher.The Ethologische Gesellschaft association awards the "Niko Tinbergen Prize" once in two yearsto outstanding post-doc level researchers in behavioural biology .

7.4.3 Karl Ritter von Frisch (1886 – 1982) :

He was an Austrian ethologist .He studied at the University of Munich and received his doctorate in zoology in 1910. He **is noted for his studies of insect behaviour and sensory physiology. He** pioneered studies in bee communication and foraging. Munich University. Breslau University Germany. Frisch was director of the zoological institute in Munich from 1925 until World War II and again from 1950 to 1958. He received numerous honors, including the Balzan Foundation Award in 1963 and foreign memberships in the United States National Academy of Sciences and the Royal Society of London . He published remarkable research work on bees. He demonstrated that -

(I) Honey bees can see colours like white, yellow, blue and violet. They can see ultra violet rays.

(II) Honey bees use a dance language called waggle and circle dance to communicate with each other. More will be explained in unit 10.

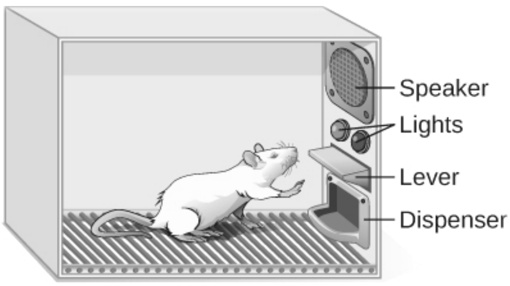
In his honour , the prestigious "Karl Ritter von Frisch Medal" of the German Zoological Society (Deutschen Zoologischen Gesellschaft, DZG) is awarded every two years to scientists whose work is distinguished by extraordinary zoological achievements .

7.4.4 Burrhus Frederic Skinner (1904 – 1990):

He was an American behaviourist, author, inventor, and poet . He was Professor of Psychology at Harvard University from 1958 until his retirement in 1974.Experimental studies of behaviour in the laboratory, using manipulation.

Skinner received a Ph.D. from Harvard in 1931, and remained there as a researcher until 1936. He then taught at the University of Minnesota at Minneapolis and later at Indiana University, where he was chair of the psychology department from 1946–1947, before returning to Harvard as a tenured professor in 1948. He remained at Harvard for the rest of his life.

Skinner explained that the behaviour could be shaped, or controlled, by controlling the rewards and punishment(reinforcements) as it encourages and discourages behavioural response, he called it Behaviourism, or The Law of Effect . Professor devised a box to perform his experiments called Skinner box.



In this, a rat was closed in a box , was kept hungry. Rat explored the surroundings, and by chance, pressed the lever, and suddenly food came in the dispenser. After few trial , rat learnt how to get food ! The box also had speaker and light, you will read more about his work when you read unit 11.

7.4.5 Harry Frederick Harlow (1905 –1981):

An American Psychologist who provided a new understanding of human behaviour and development through studies of social behaviour of monkeys.

His research contributions in the areas of learning, motivation, and affection have major relevance for general and child psychology.

He is best known for his studies on maternal-separation and social isolation experiments on rhesus monkeys, which demonstrated the importance of care-giving and companionship in social and cognitive development. He conducted most of his research at the University of Wisconsin–Madison USA where he was a professor.Harlow attended Stanford in 1924 and subsequently became a graduate student in psychology, working directly under Calvin Perry Stone, a well-known animalbehaviourist. He received PhD in 1930. Details of his work will be explained in unit 11.

Harlow received numerous awards and honours, including the Howard Crosby Warren Medal (1956), the National Medal of Science (1967), and the Gold Medal from the American Psychological Foundation (1973).

7.4.6 Richard Dawkins(born 1941):

British ethologist, evolutionary biologist , Dawkins came to prominence with his 1976 book "The Selfish Gene", which popularised the gene-centred view of evolution and introduced the term "meme" (the behavioural equivalent of a gene). In 1982, he introduced into evolutionary biology the influential concept that the phenotypic effects of a gene are not necessarily limited to an organism's body, but can stretch far into the environment, including the bodies of other organisms. This concept is presented in his book The Extended Phenotype.

From 1967 to 1969, he was an assistant professor of zoology at the University of California, Berkele, USA. he returned to University of Oxford, UK in 1970, taking a position as a lecturer. In 1990, he became a reader in zoology. In 1995, he was appointed with the intention that the he will make important contributions to the public understanding of scientific field.

Dawkins is an atheist, a patron of the British Humanist Association, and a supporter of the Brights movement. In his 1986 book "The Blind

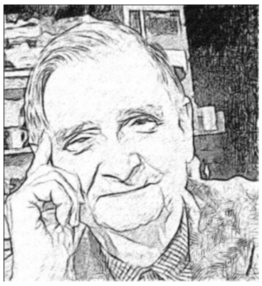
Watchmaker", he argues against the existence of a supernatural creator based upon the complexity of living organisms. Instead, he describes evolutionary processes.

He has since written several popular science books, and makes regular television and radio appearances, predominantly discussing these topics. In his 2006 book "The God Delusion", Dawkins contends that a supernatural creator almost certainly does not exist and that religious faith is a delusion. More than two million copies of this were sold.Later this book had been translated into many languages. Dawkins founded the Richard Dawkins Foundation for Reason and Science to promote the teaching of evolution .

He has many awards and recognitions to his credit. Has written many books. The Selfish Gene(1976), The Extended Phenotype.(1982), The Blind Watchmaker(1986), River Out of Eden(1995),Climbing Mount Improbable (1996), Unweaving the Rainbow (1998),A Devil's Chaplain(2003), The Ancestor's Tale (2004),The God Delusion(2006), The Greatest Show on Earth: The Evidence for Evolution(2009), The Magic of Reality (2011). Details of his work is mentioned in unit 9.

7.4.7 E. O. Wilson(born 1926):

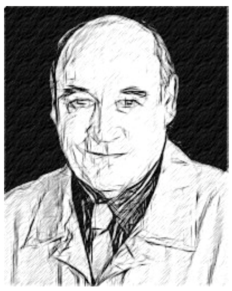
Harvard University, USA, known for Coining the term 'sociobiology‘; winner of Pulitzer Prize (1979),Crafoord Prize (1990),Pulitzer Prize (1991),Kistler Prize (2000) and Nierenberg Prize (2001) entomologist, naturalist, and environmentalist .Edward Osborne Wilson (born 1929) is an American biologist, researcher (sociobiology, biodiversity), theorist , naturalist ,conservationist and author. His biological specialty is myrmecology, the study of ants.Wilson is a two-time winner of the Pulitzer Prize for General Non-Fiction. He is known for his scientific career he is known as "the father of sociobiology", There is EO Wilson biodiversity foundation in USA. EO Wilson is a Professor and Curator of Entomology at the Museum of Comparative Zoology at Harvard University. Details of his work is explained in unit 9.



7.4.8 Desmond Morris(Born 1928) :

He is a world-renowned anthropologist, zoologist, author and painter. Dr Morris was born in Wiltshire in 1928 and educated at Birmingham and Oxford universities. He has been a Zoological research worker. University of Oxford (1954-56), Head of Granada TV and Film Unit at Zoological Society of London (1956-59), Curator of Mammals at Zoological Society of London (1959-67) , and he was Director Institute of Contemporary Arts, London . from 1967-68.

Desmond Morris publishes 48 valuable scientific papers between 1952-1967.He has written 50 popular books between 1958 and 1999.His TV programmes are Zoo time (1956-67), Life (1965-67) ,The Human Race (1982) ,The Animals Road show (1987-89) ,The Animal Contract (1989) ,Animal Country (1991-96) ,The Human Animal (1994) and the latest was the Human Sexes (1997) .Morris was educated in UK ; he was awarded a D.Phil. from Oxford University for his thesis on the Reproductive Behaviour of the Ten-spined Stickleback, supervised by Nobel Laureate Niko Tinbergen. He was employed by theZoological Society of London as Curator of Mammals at the London Zoo .Morris first came to public attention in the 1950s as a presenter of the ITV television programme Zoo Time, but achieved worldwide fame in 1967 with his book The Naked Ape. His later studies, books and television shows have continued this focus on human behaviour, explained from a zoological point of view.



Desmond Morris has published more than 80 books, some popular ones are **:**1964. Apes and monkeys ; 1965. The mammals: a guide to the living species;1966. Men and apes;1967. Primate ethology;1967. The naked ape;1969. The human zoo; 1977. Manwatching ; 1979. Gestures;1985. Bodywatching; 1990. Animalwatching ;1991. Babywatching ;1994. Bodytalk ; 2002. People watching; 2008. Baby ;2010. Child; how children think, learn and grow in the early years and 2014. Leopard

7.6 Summary

After reading this unit you know that anything that animal performs is included in behaviour. Systematic scientific study of animal behaviour is called Ethology. People who study animal behaviour are called Ethologists. Pre Historic men have been keen observer of animals, they used to make drawings in caves . We are all interested into how our pet and domestic animals behave. We must know about other animals sharing earth with us. We are all inter woven into a delicate network essential for each other"s survival. Animals perform two types of behaviours one that are genetically determined and are fixed and ridged called innate, and the other type is flexible which animals learn by experience called learned.

There are many scientists and naturalists who initiated the study of animal behaviour. Three names are known all over the world. Konrad Lorenz, Niko Tinbergen and Karl Von Frisch who had won the Nobel prize in 1973 for their work in ethology.

7.5 Glossary

- **Behaviour:**Behaviour includes all gestures, postures, expressions, movements animals make. All vocalization, colour change, emission of light and pheromones
- **Ethology:** Systematic and scientific study of animal behaviour**.**
- **Ethologist:** A person who studies animal behaviour**.**
- **Fixed Action Pattern:** Alsoknown as Innate,Inborn and inherent behaviour**,** genetically pre wired/predetermined
- **Sign Stimulus:** Behaviour specific, species specific stimulus to release a fixed action pattern.
- **Learning** : Any behaviour acquired due to experience by watching others.

7.6 Self-Learning Exercise

Section -A (Very Short Answer Type)

1. Nobel prize in animal behaviour was given in the year.........
2. Who is known as father of Ethology?.........
3. Who proposed that behaviour could be shaped, or controlled, by controlling the rewards and punishment or reinforcements as it encourages and discourages behavioural response . ...
4. .... studied bees.
5. EO Wilson is known as father of ....

Section -B (Short Answer Type)

1. Define Behaviourism or The Law of Effect
2. Define Fixed action pattern
3. Explain Sign Stimulus
4. What is Harlow known for?
5. Name any six books by Desmond Morris.

Section -C (Long Answer Type)

1. Differentiate between Innate and Learned behaviours
2. Write a note on Konrad Lorenz
3. What mechanisms control behaviour?

Answer Key of Section-A

1. 1973
2. Konrad Lorenz
3. Skinner
4. Karl Von Frisch
5. Sociobiology

Unit -8

Approaches and Methods in Study of Behaviour

Structure of unit:

8.0 Objectives

In this unit You will understand how animal behaviour can be studied in lab and wild. Part one deals with how brain controls behaviour and what techniques are used for that purpose. Part two of the unit will deal with how free ranging animals are studied in wild.

8.1 Introduction

Study of animal behaviour can take place :

(1) **In Wild :**There is again no restriction on the type and size of animal. Amphibian to mammals can be observed , if the terrain and climate permit. Animals are studied in their natural environment . Animals are allowed to roam around freely .

(2) **In Lab :**Behavioural experiments are carried on small to medium sized animals such as invertebrates , frogs, fish, pigeons, doves and on small mammals (rat, mice, hamster, guinea pigs , cats, dogs and apes) .These animals can be operated, or animals are subjected to psychological tests like maze, jumping box , Thorndike box , Skinner box , they are tested over grids , wheels . This unit specially deal with the study of brain and behaviour by surgical , chemical and electrical methods.

(3) **In Zoo :**There is no restriction on the type of animal . It can be from rat to rhino , from eel to elephant . Any animal that can survive in captivity can be studied in zoo for its behaviour .In zoo , the recording of behaviour is purely by ocular observations i.e. by looking at the animal. No surgery or handling of animals id done. This part is not included in your syllabus.

8.2 Methods of studying population of wild animals (line transect, quadrate, mark recapture methods)

These methods are generally used to census/count animals in wild. Census is a count or survey of a population; population is a group of individuals of the same species living in a particular geographic area; population ecology concentrates mainly on the factors that affect how many individuals of a particular species live in an area. Estimates of plant populations are generally simplified by the fact that plants don't move and are usually quite easy to find. Animals, on the other hand, are mobile and in many cases very difficult to find. For animals, special techniques are required.

Surveys are done to know about the number of animals, their diversity, distribution, density, relative density, dominance, relative dominance, frequency, relative frequency and abundance.

Why is it important to count wildlife regularly? Number of wild animals does not change rapidly; the changes are small and slow, regular counts at regular interval are necessary to detect change in their population that help in their management.

1. The most important thing is to define/decide your objective.
2. The type (species and sex) of animals, the habitat in which it is found

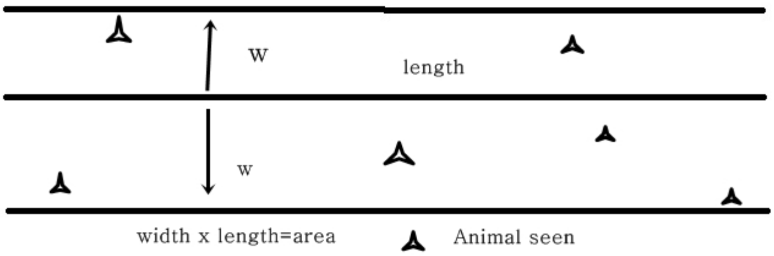
3. The number of animals seen
4. Time and season when the animals were seen, vegetation around them
5. By what method the animals were counted, (e.g. aerial, water or ground count; direct or indirect count).

Different counting methods are applied to different animals. For large animals like Rhino, elephant, Hippo, Giraffe the direct count method could be utilized, while specific sampling methods are used for small and medium sized animals.

Total count : A complete count, or total count, counts every member of a population. Where populations are small, it is possible but if large number of species and individuals it is impossible to count them. Some time total count of colonial animals is possible such as of waterfowl on lakes, seals on breeding beaches, or elephants in grass land by aerial counts or by taking their video and photographs to be counted later in the lab. Total counts rarely used because it is not possible to count animals in a large area, however, it can only be done if: 1. The animals are small, they live in small area 2. The animals are large and they are confined to small areas. Therefore, samples of populations have to be counted to get an estimate number of animals to have an idea about their population. How are sample surveys done? There are four common ways of doing sample surveys, these are: 1. by foot - walked transects, quadrates,2. By vehicle - road strip or belt counts,3. By aircraft - aerial surveys by taking movie or using transect and quadrate and 4. by ship- boat, using sonar.

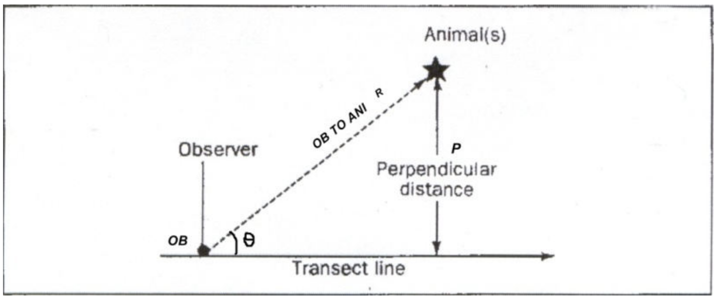
8.2.1 Transect (Fixed width)

Basically Transect sampling is one of the most widespread ecological techniques for sampling both plants and animals. To implement this technique, the investigator establishes a line (i.e., the transect line) between two points. This sampling is easy and relatively inexpensive for many biologists to use for population estimation. This method is typically used for mobile organisms. The researcher walks along the transect, recording individuals encountered .When the area is large, and you can not cover the whole of it, but you want to know the density (animals per square kms), estimation techniques are used. A small sample is taken. Its length and width are predetermined , and so is its area (length multiplied by width gives you area), you walk along that length and keep counting animals that you see on both sides (fixed, predermined width) of the length. At the end you have the length, width, multiply it to get area. Divide number of animals seen by area, you will get the density of animals.



8.2.2 Line transect (variable width)

This method is little tedious, because here the width is not known. A researcher walks on the transect, whose length (L) is known. The scholar wishes to calculate density of three large herbivores-neelgai , sambar and chital .



L = transect line ;ob = position of observer; animal = position of animal

W = has to be calculated later, by using values of r and θ ; r = sighting distance; θ (theta) = sighting angle ;P = perpendicular distance (Perpendicular distance is used to calculate width of the transect and the formula is P = r sin θ).

(1) The scholar has to record number and species of these animals seen all along the length of the transect.

(2) He/she has to measure distance between him and the animal (r)

(3) Note the angle (θ) between r and straight line of transect

(4) Use of r and θ will help calculate value of perpendicular distance (P)

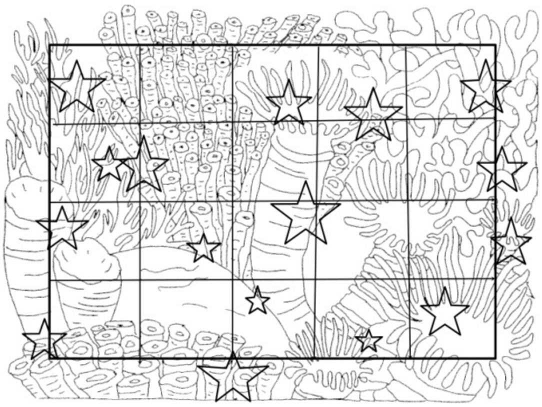
(5) $P = r \sin \theta$

(6) mean of all Ps will give the width of transect

After finishing the transect you may have a variety of Ps, add them and take the mean it will give you width of the transect. Multiply this width with length to get the area of the transect. If you divide number of animals with area, it will give you the density.

8.2.3 Quadrat method (sampling sedentary organisms):

A Quadrat is a frame usually a square . The use of a quadrat is very simple: It is placed randomly in the sampling area (the habitat of the species of interest) and all the individuals within the quadrat are counted and/or measured. Once a plot has been established, the total number of individuals of each species can be counted to determine population densities and species composition.



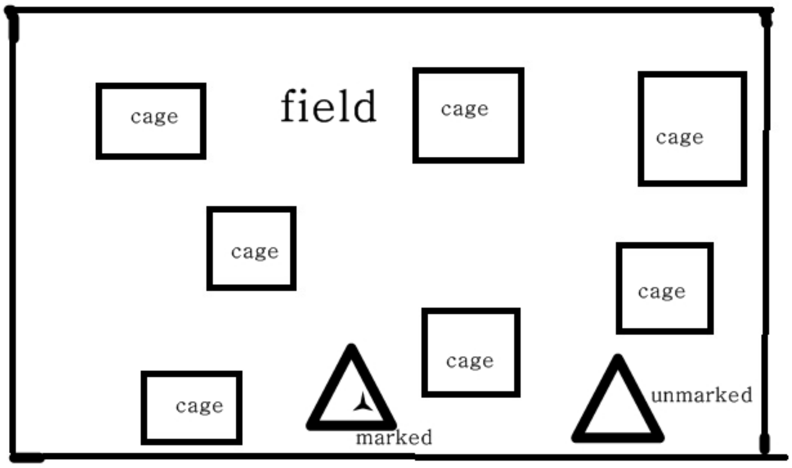
Here is one example:

1. You wish to know the density of starfish
2. You lay 10 quadrates, each measures 2x2 mts. Area 4 sq mt
3. The total area of all Quadrats is 40 sq mt
4. suppose starfish counted in all Quadrats are 412
5. Number of animals /area=density

412/40 =10.3 starfish per sq mt

8.2.4 Mark-Recapture Method:

This method is known by many names viz-capture-recapture, capture-mark-recapture, sight-re-sight and mark-release-recapture .This method provides a way to measure population sizes of individual animal species. In theory, mark / recapture techniques involve sampling a population of animals and then marking all of the individuals captured in a recognizable way. The marked animals are then released back into the population and left to mingle for a suitable period of time. Once they have become thoroughly mixed into the population again, the population is re-sampled. We shall need cages to capture and recapture animals. For example you wish to find out the number of desert rat in a field using mark and recapture method. We put few cages in 1 sq km area.



(1) In order to find out the number of rats in the field 7 traps are put, in area of interest
(2) Cages were checked after two days
(3) Suppose 4 cages had one rat each (first sample) this is = n1
(4) Mark these 4 rats with colour(called marked rats)
(5) These marked rats are released back into the same field
(6) All the cages are checked again after 3 days
(7) This time suppose all 6 cages had a rat (second sample) this is= n2
(8) check how many of them has a colour mark, this is =m2

calculate using following :

N= n1 x n2 / m2

Where N is the number of rats we wish to estimate

n_1 = Number of animals 1st marked and released -it is 4

n_2 = Number of animals captured in 2nd sample - it is 6

m_2 = Number of marked animals in 2nd sample- it is 3

Put the values :

N=n1xn2 divided by m2

=4x6/ 3 =8 rats /sq km

8.3 Methods of studying behaviour in lab with special reference to brain (neuroanatomical and neurochemical)

8.3.1 Neuroanatomical

8.3.2 Neurophysiological and chemical

8.3.1 Neuroanatomical or lesion or ablation technique:

This is the oldest and also most crude method in neuro ethological research for studying the relationship between particular neural structure and behaviour. In this crude method in earlier times certain regions of the brain were destroyed and their function was deduced from the abnormal behaviour it caused in the animal. The larger ablation (removal of tissue) or lesion (pathological changes in tissue) were carried out free hand by knife cuts; whereas, the localized and small lesions are produced by passing electric current through platinum, iridium electrode to cauterize the area.

This technique helped many earlier workers to form brain atlases or brain maps, which are known as Stereotaxic atlases that are presently available for many mammalian species viz. rat (De Groot, 1959), cat (Jasper and Marsan, 1954) and dog (Lin and Coworkers, 1961). Brain mapping is defined as the study of the anatomy and function of the brain.

The lesions were produced by careful surgery, this particular technique was first practiced by medical doctors, who used to examine patients having head injury. Doctors observed that patients showed peculiar behavioural changes due to injury in head, it was rightly correlated by them that behaviour is controlled by brain. While performing the operations, or post-mortem autopsies the destructed areas of brain were identified, and impairment in behaviour was correlated with it, indicating direct influence of brain over behaviour.

Broca (1861) was a doctor ,who came across a patient with head injury whose speech was defective, this correlation fascinated him and he started observing different patients with similar injuries. After few years, he concluded that there is a definite area in the cortex in frontal lobe which is responsible for speech.

Later using the same technique another scientist-Wernick (1880) established another area in the brain in temporal lobe responsible for speech.

These two areas are known as Broca's ana Wernick's areas respectively.

Broca's area controls the infrastructure for speaking a word, this means it has control over neck muscles and larynx, and Wernick's area is word retriever or has the dictionary where all words that we learn are stored.

A lesion in Broca's area causes slurring in speech and there is difficulty in understanding the words spoken by such a person though the person would talk sensibly. Opposite to it, if there is a lesion in Wernick's area then the person can talk clearly but the speech will not be articulated or coherent.

This technique was considered too crude, and was used less by next generation of scientists. The new methods evlved called neurophysiological and chemical methods. (But in modern times ablation method has caught up again, due to the discovery and use of laser , which is capable of making very precise and minutest ablations).

8.3.2 Neurophysiological technique:

As mentioned earlier ablation or lesion methods were dropped by scientists due to their crudeness . By removing piece of brain a huge disturbance was created to nearby area. Brain has enormously complicated net work of axons and dendrites criss crossing all over. The newer methods were based on the discoveries that messages in brain are passed on using electrical current and chemicals called neuro transmitters.

The discovery of bioelectricity came by chance. The Italian scientist Galvani (1786) hung some frog legs on his balcony railing one day and noticed that the legs twitched when they' touched the metal fence. This finding laid the foundation for electrophysiology.

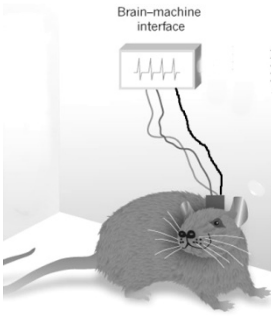
The discovery that the messages in nervous tissue travel in the form of electric current led to a less destructive and more precise neurophysiological method to study behaviour.

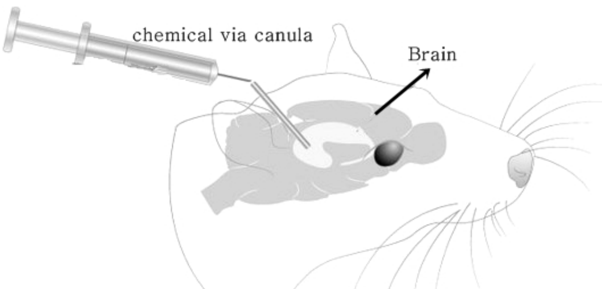
At the end of the 19th century, Ferrier was able to roughly localize in the cerebral cortex- the sensory centers for vision, auditory, gustatory and olfactory sensations.It became technically possible to record the electrical potential of active nerves with the aid of implanted electrodes and to amplify this activity by a highly sensitive instrument, where it could be detected and measured.

This technique has now become a routine tool of neurophysiologists and neuroethologists. The procedure involves implanting electrodes in the brain and used in two ways :

(1) Recording of electrical activities from brain while animal is behaving.
(2) Stimulating the brain region and eliciting behaviour.

Later it was studied that neurons are affected in their activity by local application of neuro-transmitters. To locate the exact centre in the brain the drugs are directly poured or introduced into different places of brain and when the person describes a feeling of well being it is ascertained by the experimenter that this particular part is the centre for pleasure. Fisher in 1956 showed that sexual and maternal behaviour can be induced by the injection of minute quantities of sex hormones' 'the regions of hypothalamus.





Now the latest is brain imaging techniques CT (computerized tomography) MRI (Magnetic resonance Imaging), PET(Positron Emission Tomography) and SPECT(Single-photon emission computed tomography) have come into practice.

8.4 Summary

This unit teaches you how to study behaviour of animals in wild and in lab. In wild, there are many methods, but here you have only read about how to find out the density of animals in forest using line transect, quadrat and mark recapture methods. The other methods explain you how brain is studied to find out what part of brain controls which behaviour. In Neuro ablation technique, part of brain was removed and animal was observed which behaviour is lacking? A correlation was made and brain maps were formed. This method was considered crude and newer methods using neuro physiological and chemical techniques evolved.

8.5 Glossary

- **Census-** counting of animals to know about their population
- **Density-** animals per square unit
- **Fixed width transect-** Used for finding out density of animals in an area. Fixed length, fixed width on both sides of transect
- **Variable width transect-** Used for finding out density of animals in an area Fixed length, variable width, average to be calculated
- **Quadrate method-**Used for finding out density of animals in an area ,used for sedentary animals. All animals are counted present in quadrat.
- **Mark recapture method**- Used for finding out density of animals in an area Animals are captured, marked, released, recaptured and by using a calculation density is found out.
- **Neuro anatomical-**Used to study what part of brain controls which behaviour. Part of the brain is removed, considered a crude method. But earlier scientists used it successfully to make brain maps.
- **Brain map-** Brain mapping is further defined as the study of the anatomy and function of the brain
- **Neuro physiological-** Use of electric stimulation and recording
- **Neuro chemical** - Use of Neuro transmitters and drugs to study brain and behaviour
- **CT -** computerized tomography
- **MRI-** Magnetic resonance Imaging
- **PET**- Positron Emission Tomography
- **SPECT**-Single-photon emission computed tomography

8.6 Self-Learning Exercises

Section -A (Very Short Answer Type)

1. write full forms of CT,MRI,PET and SPECT
2. The dictionary or words in brain is located in..........................

3. The area having centre for infrastructure to speak a word is called....
4. Brain maps are also known as ....atlases
5. Lin and Coworkers... had prepared brain map of ...... in the year

Section -B (Short Answer Type)

1. Define density giving an example.
2. What are the four common ways of doing sample surveys ?
3. Write briefly on fixed width transects
4. Write briefly on and variable width transect
5. Describe quadrat method briefly.
6. Write a short note on nerophysiological technique.

Section -C (Long Answer Type)

1. Explain Fixed width Transect method
2. Describe Quadrat method
3. What do you understand by mark recapture method. Explain by example.
4. Why is neuro physiological, chemical techniques are better then neuro anatomical technique?

Answer Key of Section-A

1 CT - computerized tomography ,MRI- Magnetic resonance Imaging,PET- Positron Emission Tomography, SPECT-Single-photon emission computed tomography

2 Temporal lobe

3 Broca's area

4 Stereotaxic

5 Dog, 1961

Unit - 9

Human Behaviour and Sociobiology

Structure of the Unit :

9.0 Objectives

This is a big unit, you will know how Human brain looks and what part controls which behaviour, how your emotional equilibrium is maintained by limbic system situated deep inside the brain, hypothalamus is a tiny structure, not bigger than your little finger nail but has centres of feeding ,drinking, sexual and maternal behaviours .

The brain stem (pons and medulla oblongata) houses net work of reticular formation to make us sleep and wake. This mechanism is under the control of Biological clocks (daily, annual, lunar).How study of these clocks are called chronobiology. Our objective is to make you understand how bird migration and navigation is also under biological clock.

Next part of the unit is oriented towards explaining you social behaviour on animals and the advantages of living in social grouping, we shall take examples from social groups of monkeys and bees.

Last part of this unit will introduce you to a modern concept of Sociobiology . You would learn about the evolutionary significance of behaviour. The objective is to get you familiar with terms like Darwinian fitness, individual fitness, kin selection and group selection.. We wish to teach you how cooperation, reciprocation and altruism(sacrifice) shown by animals is beneficial to them in terms of evolution.

9.1 Introduction

This is a large unit, you shall be covering three big parts related to the study of animal behaviour. This unit is divided into five major parts, as mentioned above. Each has its own introduction. You shall read introduction of each part separately.

MacLean identified 3 basic brain drivers of the neural chassis, and these drivers create The Triune Brain concept: (1)The Reptilian Brain (or R-complex), also known as "reptilian brain" the name was given to the hypothalamus-seat of instincts such as feeding, drinking, mating, nesting, aggression, dominance, territoriality, and ritual displays. (2) Paleo-mammalian brain or the Limbic Brain. MacLean first introduced the term "limbic system" to refer to this set of interconnected brain structures in a paper in 1952 , responsible for emotions.

(3) Neo-mammalian complex or The Neo-cortex-a structure found uniquely in mammals. MacLean regarded its addition as the most recent step in the evolution of the human brain, conferring the ability for language, abstraction, planning, and perception.

9.2.1 Human brain and behaviour:

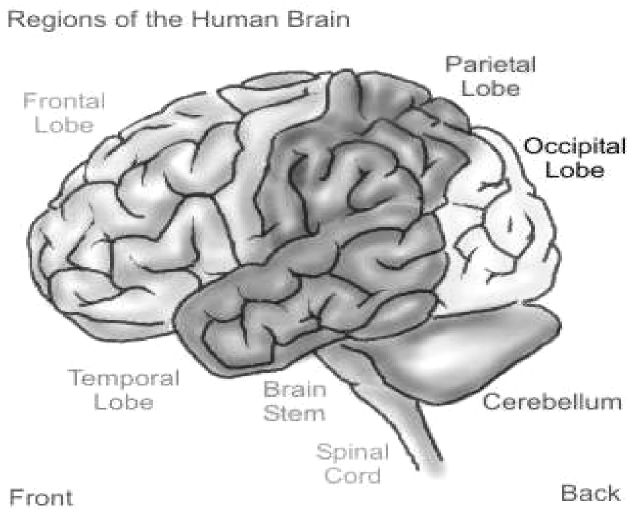
It is the most complex organ of the body , weighs about 1,300 grams. Contains billions of neural networks that interact to create innumerable numbers of functions.

So let's start with Human brain and behaviour, limbic system, hypothalamus and reticular formation. You may have studied in your previous classes that the brain three main parts:

(i) Forebrain (Prosencephalon)- cerebral cortex, thalamus, hypothalamus),

(ii) Midbrain (Mesencephalon) -tectum and tegmentum), and

(iii) Hindbrain(Rhombencephalon) - cerebellum, pons and medulla or brainstem).



Fore brain (Prosencephalon) :

Cerebral Cortex - The cerebral cortex is a layer (1.5mm to 5mm thick) in the brain which is mostly made up of gray matter, it plays a key role in memory, attention, awareness, thought, language, and consciousness. Below that, is the white matter called the **Cerebrum** which is divided into many lobes and two hemispheres .

Frontal Lobe

The Frontal Lobe of the brain is located deep to the Frontal Bone of the skull. Covers $1/3^{rd}$ of area of the brain. It plays an integral role in the following functions/actions:- Memory Formation ,Emotions, Decision Making, Reasoning and Personality.

It has three distinct areas 1.Silent /prefrontal area which has centres for association, thinking, judging, worrying, day dreaming, intuition, reasoning, planning and problem solving 2.Premotor area - that controls learned skilled movements, eye movements and lastly 3.Primary motor /motor cortex responsible for all muscle movements.Only on the left side it has **Broca's area** which controls infra structure related speech (larynx and neighbouring structures helpful in speaking a word properly).

Parietal Lobe- The Parietal Lobe of the brain is located below the Parietal Bone of the skull. It plays a major role in -Senses. All sensory cortex is found here , body's own Spatial awareness in space, this means it helps you orient yourself in space and helps you sit on the stool and not fall on the ground. It also has centres for heat, pain, touch ,cold, pressure .

Occipital Lobe- This lobe has two major areas1.Primary Visual Cortex – responsible for sight , recognition of size, color, light, motion, and dimensions.2.Visual Association Area – which interprets information acquired through the primary visual cortex, associated with visual processing of shape, size, colour, texture and depth .

Temporal Lobe-This lobe also has three main areas 1. Primary Auditory Cortex which is responsible for hearing **2.** Primary Olfactory Cortex – which Interprets the sense of smell once it reaches the cortex via the olfactory bulbs. and 3. Wernicke's Area – located only on the **left** side of Temporal and it has the dictionary of words, that we learn all through our lives. This lobe is associated with perception and recognition of auditory stimuli, memory, and speech.

Entire cerebral cortex is divided into two large hemispheres-left and right. They both remain connected by tissue called corpus callosum.**Left hemisphere** for most people is the dominant hemisphere. The left hemisphere controls the right side of the body , Produce and understand language responsible for production of language, mathematical ability, problem solving and logic, this hemisphere is predominantly scientific, whereas, **right hemisphere** is responsible for and creativity . Music and art appreciation, dance, fantasy have centres in right hemisphere. This is largely artistic.The right hemisphere controls the left side of the body , temporal and spatial relationships ,it analyzes nonverbal information.

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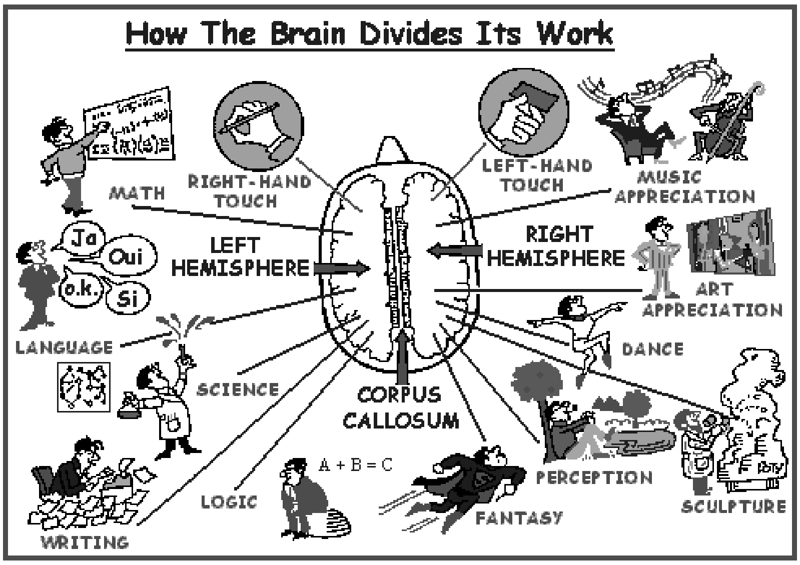

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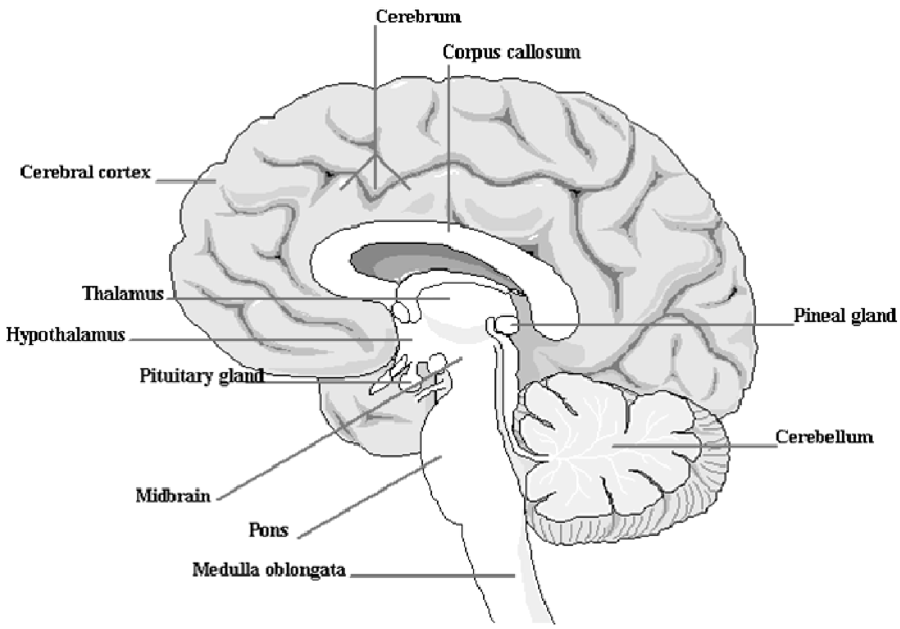
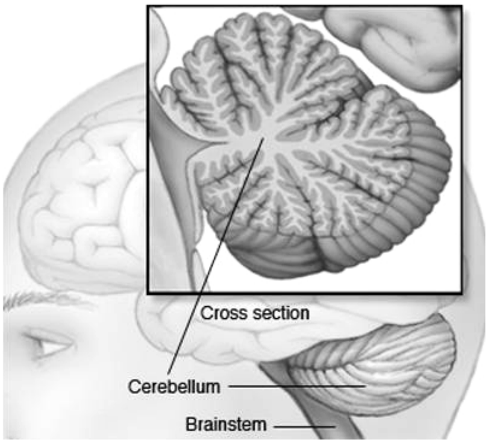


Thalamus- filters sensory information, controls mood states and body movement associated with emotional states. It is a midline paired symmetrical structure within the brains of vertebrates. It is situated between the cerebral cortex and midbrain. Its functions include relaying sensation, spatial sense, and motor signals to the cerebral cortex, along with the regulation of consciousness, sleep, and alertness. This structure is associated with regulation and coordination of movement, posture, and balance.

Midbrain(Mesencephalon -tectum and tegmentum): The midbrain comprises the tectum , tegmentum, the cerebral aqueduct . These structures have one big function- connect forebrain with hindbrain. They act as a bridge.

Hind brain (Rhombencephalon)-

Cerebellum- regulates equilibrium, muscle tone, postural control, fine movement and coordination of voluntary muscle movement. Motor actions are initiated in motor cortex of frontal lobe, but are coordinated in cerebellum. A cricket bats man coordinates its strike using this part of the brain. It's called small brain, it is located at the back adjoining pons. It has convoluted leaf like structures.



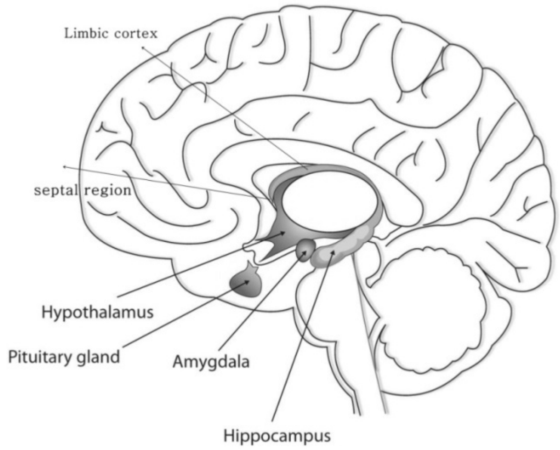
Pons- Relay station between cerebrum and cerebellum

Medulla oblongata- Conscious control of skeletal muscles, balance, co-ordination regulating sound impulses in the inner ear, regulation of automatic responses such as heart rate, swallowing, vomiting, coughing and sneezing.

9.2.2. Limbic system

What is a system in brain? Different nuclei work towards carrying out one function . This is called system. **James Papez** in 1937 first proposed that this system help us maintain our emotional equilibrium. Phylogenetically, the limbic system is one of the more primitive parts of the brain. It has a central role in memory, learning, emotion, neuroendocrine function, and autonomic activities. Functionally important nuclei in limbic system are :
(i) **Hippocampus and (ii) Amygdala**

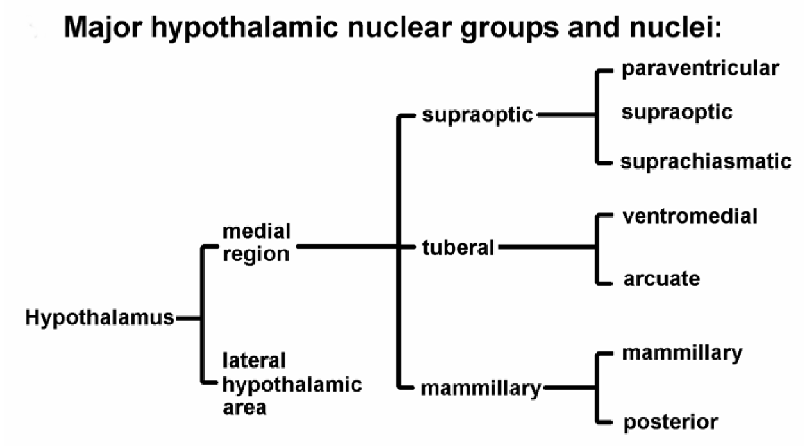
(i) The Hippocampus is important in memory and learning, Memory processing, it deals with basic drives, emotions, and memory. Hippocampus is very important in converting short term memory into long term memory. If the hippocampus is damaged, a person cannot retain new memories, that person will ask your name again and again. But older memories earlier then damage remains.Hippocampus also plays part in Attention, Sexuality , Appetite and Thirst



(ii) Amygdalacontrols aggression (fight) , fear (flight), also involved in drives, emotions, and memory.The amygdalas are two almond-shaped masses of neurons on either side of the thalamus . When it is stimulated electrically, animals respond with aggression. And if the amygdala is removed, animals get very tame and no longer respond to things aggressively. It mediates and controls major mood states such as friendship , love, affection and fear.

9.2.3 Hypothalamus

The hypothalamus is a very complex part of the brain. It contains a number of different types of specialised nerve cell and controls different physiological functions. Hypothalamus is an accumulation of tiny nuclei. It is known as 'Central control' for master gland i.e pituitary gland. Regulates autonomic, emotional, endocrine and somatic function. Has a direct involvement in stress and mood states. The hormones produced by this area of the brain govern body temperature, thirst, hunger, sleep, circadian rhythm, moods, sex drive, and the release of other hormones in the body. This area of the brain controls the pituitary gland and other glands in the body. This area of the brain is small, but involved in many necessary processes of the body including behavioral, autonomic, and endocrine functions. The hypothalamus' primary function is homeostasis. Hypothalamus has many nuclei :



Hypothalamus has two major areas Medial and Lateral. Medial has three nuclear groups-supraoptic, tuberal and mammillary. Supraoptic has three nuclei-paraventricular ,supra optic and suprachaismatic . Tuberal has two nuclei -ventromedial and arcuate, mammillary has two nuceli- mammillary and posterior. Lateral hypothalamic area is large and has no further divisions. Their functions are as follows

Paraventricular nucleus: . It is a complex structure in the hypothalamus , this regulates appetite , neuroendocrine secretions and autonomic functions .It is a major source of vasopressin and of corticotropin-releasing factor. Many neurons project directly to the posterior pituitary where they release oxytocin and vasopressin into the general circulation.

supra optic nucleus :. The supraoptic nucleus is neurosecretory. Antidiuretic hormone is released in response to to sodium concentration in blood. So it regulates, thirst and water in blood. Oxytocin neurons are also present here, they respond to stimulation of the nipples (resulting in milk production) and in response to uterine contractions and distension of the birth canal.

The suprachiasmatic nucleus (SCN) is a tiny region located in the hypothalamus, situated directly above the optic chiasm. It is responsible for controlling circadian rhythms. The neuronal and hormonal activities it generates regulate many different body functions in a 24-hour cycle.

The ventromedial nucleus (also referred to as the ventromedial hypothalamus) is a distinct morphological nucleus involved in feeding, fear, thermoregulation, and sexual activity. This nuclear region is also involved with the recognition of the feeling of fullness.

The arcuate nucleus is a small part of the hypothalamus that plays an extremely important role in the regulation of hormone secretion from the pituitary gland, and in the regulation of appetite and body weight.

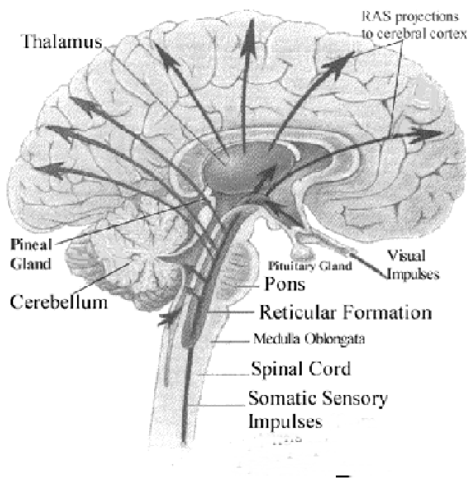
The mammillary bodies are a pair of small round bodies, located on the under surface of the brain . These bodies are connected directly to the brain, and they relay impulses to the thalamus . Additionally, the bodies appear to be very important in forming and recalling memories. Destruction or injury to these portions of the brain is often associated with amnesia (loss of memory). They also help biological clock run.

The posterior nucleus of the hypothalamus functions in thermoregulation (heating) of the body. Damage or destruction of this nucleus causes hypothermia.

The lateral hypothalamus or lateral hypothalamic area, (LHA) . It is involved in hunger . Damage to this area can cause reduced food intake. Stimulating the lateral hypothalamus causes a desire to eat.

9.2.4 Reticular Formation

Nuclei in brain stem (medulla oblongata) work together in initiating sleep and arousal , maintaining consciousness, alertness and attention . Sensory impulses pass through this formation to reach cerebrum. Reticular formation (RF) remains under the control of biological clock(you are about to read about them in this unit). As the night falls, biological clock send signals to RF, that its time to sleep. The neural activity of sensory nerves start falling stopping them gradually and completely. consequently, neural activity in cerebrum also falls and person goes off to sleep. In morning opposite to this happens. Biological clock sends a wake up message to RF, slowly increasing the neural activity and the person wakes up. Injury to the reticular formation can result in irreversible coma.



9.3 . Biological clocks (daily, annual, lunar), chronobiology; bird migration and navigation

Biological clocks are also known as internal clocks or circadian rhythms these rhythms are the internal mechanisms that provide a means of measuring length of the time of the day. This clock allows animals to adapt their behaviour and body physiology in the best possible way to the changing 24 hours, or changing seasons, or changing lunar phases.

9.3.1 Biological clocks (daily, annual, lunar)

Biological clocks are also known as **internal clocks** or **circadian rhythms** these rhythms are the internal mechanisms that provide a means of measuring length of time to the living beings. The existence of circadian and circannual rhythms means that animals must have a way of keeping track of time . Broadly these biological clocks/ internal clocks let the animal and plants predict and prepare for changes to come over the day or season. Each of the rhythms is not exactly 24 hours, you have notices their names start with **circa** (which means ‘about’).

These rhythms allow the animals to adapt their behaviour in the best possible way to the course of a day's or seasons changing events. The common example around us is of office flower or morning glory, or Portulaca which opens when the sun comes up and closes when sun sets. The birds leave for their migration at a predetermined time to arrive at the destination at a suitable time.

Biological clocks are used for:

1. Control of the daily rhythms of the body,

2. Reproduction timing,

3. Preparing for migration by eating of plenty of food,

4. Preparing for winter by storing of food,

5. Increasing thickness of coat

6. Prepare for hibernation and aestivation

All organisms have different cycles.

1) Daily cycles (**Circadian**) to cope up with day and night

2) Annual cycles(**Circannual**) to cope up with changing of the seasons

3) Lunar cycles (**Circalunar**) to cope up with changing phases of moon and

4) Tidal cycles (**Circatidal**) related to the tides

It is advantageous for an organism to be in sync with these cycles in its environment.

A **circadian** cycle has a period of about 24 hours. In other words it is about 24 hours long (one day). Examples of circadian cycles in humans include the wake/sleep cycle, body temperature changes, and heart rate (the last two drop at night).**Diurnal** - mostly active during the day, inactive at night. Eg. Humans, bees. **Nocturnal** – active at night, inactive during the day. **Crepuscular** – active at dawn and dusk. Eg rabbits and mosquitoes. **Arrhythmic** – no regular daily pattern .**Matutinal** means active only in the morning. Matutinal organisms wake up before diurnal organisms so they have the advantage of consuming resources without competition. **Vespertine** means active only in the evening ; insects and plants are observed to follow these two patterns.

A **circannual** cycle is about 365 days long (one year).Examples of annual cycles: Reproduction of animals and plants, Migrations, Leaf fall (" patjhad" abscission) ,Hibernation(winter sleep) and Aestivation(summer sleep) in animals are examples of circannual cycle.

A **circalunar** cycle is about 29 days long (one lunar month).Because the position of the moon and sun generate tidal patterns, they can affect marine organisms. Grunions are small fish that spawn on land. From April to June, when a spring tide occurs (3 or 4 times), the fish squirm onto the beach at high tide. Female releases her eggs in sand and the male wraps around her to release the sperm. They then catch the out-going tide. 15 days later, at the next spring tide, the young grunions have hatched and catch a wave back out to sea.

A **circatida**l cycle is about 12.5 hours long (one tidal cycle).Circatidal cycles affect marine organisms, particularly those which live on shorelines. Examples include feeding cycles of shellfish and other sea animals.

It has been a subject of interest whether periodicity in an animal is determined by external environmental stimuli (exogenous) or controlled through physiological factors within the animal itself (endogenous). Both the stimuli are important. Their intimate relationship was brought to notice as early as 1960 by Lorenz, neither exogenous nor endogenous stimuli are solely responsible in controlling behaviour through biological clocks, it is the intricate interaction between the two together. Initially, to set the clock and run it, external stimuli like day length, lunar phases, tides, and temperature are used. Later to maintain it functional ,internal stimuli are needed.

The biological clock in animals is found in the hypothalamus of the brain(refer to diagram below) . To remain in synchrony with the ever changing environment, biological clocks need to be **set and reset** at regular intervals. This process is called **entrainment**. The environmental cue that resets the biological clock is called the **zeitgeber** ("time giver" in German) .

9.3.2 Chronobiology

You have just finished reading about biological clocks. We took most examples from animals. Rhythmic cycles are found in almost all living organisms. Its study had now developed for the benefit of human beings as well . It's no different than biological clocks, but it will deal more with human beings. The study of "Relationship between physiology and temporal changes in their surrounding environment" is called **Chronobiology.** Halberg Chronobiology centre, University of Minnesota, USA is known for its significant research in this field. The centre has been named after its founder Director Professor **Franz Halberg,** who is known as **"the father of Chronobiology.** He was Professor of laboratory medicine and pathology, physiology and biomedical engineering.

Biological clocks are classified differently. Every time you come across new names. Again these Clocks are classified into three types 1. Ultradian 2. Circadian 3. Infradian

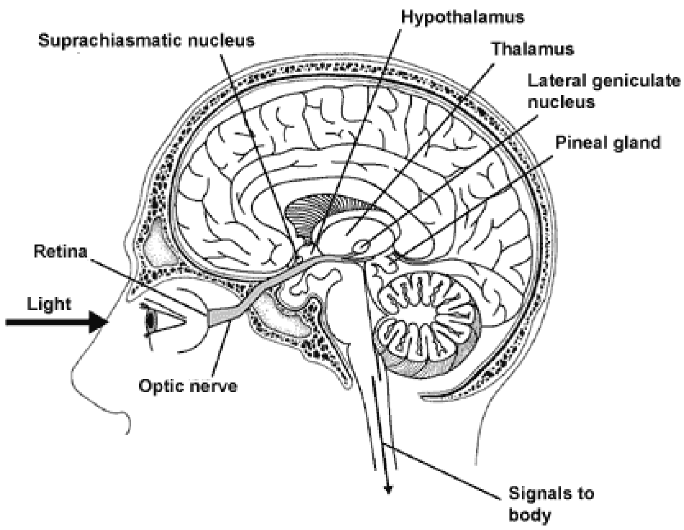
1. **Ultradian** (fast oscillating): Completed in few seconds, few minutes, few hours, half day.
2. **Circadian**: completed in approximately 24 hours
3. **Infradian** (slow oscillating) :Completed in half week, few weeks, few months, few years.

By another classification body rhythms are divided into following four types :

1. Circaseptan: A rhythm with a period of about 7 (± 3) days is seen in cell multiplication.
2. Circadiseptan: A rhythm with a period of about 14 (± 3) days.
3. Circavigintan: A rhythm with a period of about 20 (± 3 days).
4 Circatrigintan: A rhythm with a period of about 30 (±5) days. Includes, in mature women during the time of ovarian activity, the menstrual cycle.

The above cycles influence our body physiology, emotions, Psychology and even intellect.

Location of clock in human brain: The "master circadian clock" that regulates our clock in our bodies is found in supra chiasmatic nuclei (SCN) in the hypothalamus of the brain, a cluster of around 10 000 neurones. The SCN is made up of two tiny clusters of several thousand nerve cells that "tell time" based on external cues, such as light and darkness. The SCN regulates sleep, metabolism, and hormone production.



Source : http://healyourselfathomefl.health.officelive.com

The branch of **Chronobiology** dealing with the pharmacologic aspects is termed **Chronopharmacology .**Biorhythms have many medical implications , Dr. **Jarosław Ast** Department of Clinical Pharmacology, Karol Marcinkowski University of Medical Science, Poznan, Poland is known for initiating work in this field.

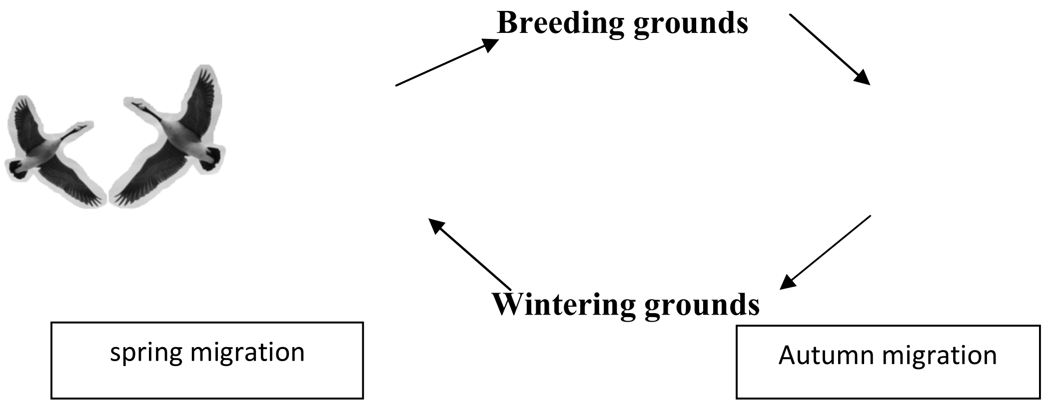
Chronotherapy is used in oncology, asthma therapy, hypertension, strokes, sleep apnoea, GI tract disorders, allergies, and immunologic disorders. When a drug is administered the pharmacological action of the drug can be predicted based on the body rhythm. In the present scenario, it is possible to explain all the functions of the body as a function of time. In the same way as sleep-wake, feed-hunger and joy-depression are regulated by the internal clocks, the maximum efficacy and minimum toxicity of a drug can be achieved if it is administered at the appropriate time; i.e., right drug in the right form, at the right dose, at the right time. So the given drug can act synergistically with biological clock.

Rheumatoid arthritis hurts most in the morning, when the body's natural anti inflammatory agents appear to be low; this is the best time to take aspirin or other painkilling drugs. Blood pressure and adrenaline peak in the morning, which may explain why so many heart attacks and strokes occur at 9:00 A.M. In asthmatics, bronchial tubes are more constricted in late evening than in morning. Study of chronobiology is becoming very useful.

9.3.3. Bird migration and Navigation

Migration: An annual two-way movement between breeding site(their home) and feeding site(their temporary home).Its a pendulum movement between these two sites. Migration is the yearly, seasonal journey undertaken by many species of birds. During this journey, birds cover distances of many kilometres. The most common types of migration are those carried out by birds in the spring(Feb-march) and the autumn (oct -nov). In the autumn, as the winters start they travel from breeding grounds(breeding ground of migratory bird is designated as its home) in the north (cold) to wintering grounds in the south(warm) and as it starts warming up (feb -march) the return journey begins). Indian subcontinent plays host to a number of migratory birds in summers as well as winters over a hundred species of migratory birds fly to India, either in search of feeding grounds of to escape the severe winter of their native habitat.

caged birds. Migratory birds start eating more before migration and store fat under the skin, they are seen flying here and there aimlessly in cage, showing a kind of restlessness, called **migratory restlessness or Zugunruhe**.



Types of Migration: There are six types of migration : (1) Daily/Local ,(2) Seasonal

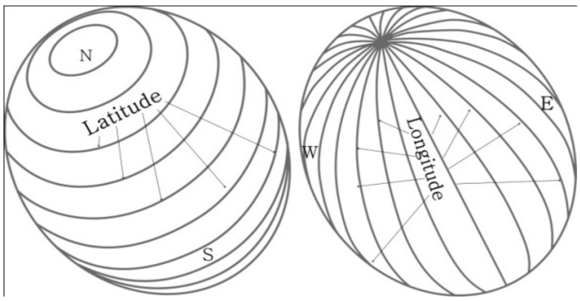
(3) Cyclic (4) Latitudinal (5) Altitudinal (6) Longitudinal

(1) **Daily local migration** :Many birds make daily movements from their nest in response to environmental forces such as light, darkness, temperature, humidity and food availability. Birds may make daily migrations from their resting sites to feeding areas. For example many common birds like house sparrow moves out every day from its resting site to feeding site in morning and returns in the evening.

(2) **Seasonal migration** :Migrations of birds in response to seasonal changes are most common. All most all the examples that you will study here fall into this category. For example, once in an year when harsh winter starts in Siberia, they fly and travel towards equator and spend time in safe water bodies. They come to Keoladeo national Park, Bharatpur, Rajasthan.

(3) **Latitudinal migration:** It is the migration from north to south or south to north. As mentioned above. It is the most common migration birds undertake . Every year millions of birds fly many kilometres from Europe, Russia towards south to the grass lands, forests and lakes of central and southern, America and Africa. many birds come to Asia. The longest latitudinal migrations are performed by several species of shorebirds. The maximum distance (about 17,600km) between the summer and winter homes of any species is that of the arctic tern. This species migrates from Canada to Antarctica, crosses the Atlantic ocean both times during its migration . In simple words migration from North to South and back is Latitudinal migration.

(4) Longitudinal migration: Movement of birds from East to West or vice-versa is known as longitudinal migration e.g. evening Gross beaks that nest in northern Michigan spend thewinter in New England, California gulls that breed in Utah migratewestward to winter on the Pacific coast, starlings move from east Europe or Asia to Atlantic ocean.



(5) Altitudinal or vertical migration: Different bird groups tend to fly at different altitudes during migration. Migrants such as hawks and vultures usually look for the advantage that thermals offer and typically migrate at 3,000 feet or less. Migrating waterfowl use a wide range of altitudes, from as low as 300 feet to as high as 10,500 feet. Most passerine species migrate at night. Over land, they usually fly at 2,100 to 2,400 feet but sometimes much lower. Over water, migration takes place at a much higher altitude, from 6,000 to 12,000 feet. Weather conditions often affect the migratory altitude as birds may fly higher or lower to avoid or take advantage of prevailing winds. Some birds have been recorded at extremely high altitudes. Bar-headed Geese migrate over the Himalayas and have been recorded as high as 27,880 feet. Species that live in mountains may adjust to changing seasons (generally during winters) by moving downward to warmer and lower altitudes where more food and shelter are also available. Coots of Andes mountains in Argentina move downwards, mountain quails, which nest at elevations up to 9500 feet in central California mountains, migrate downward to areas below 5000 feet and in summers they go back to the hill.

Distance covered by migratory birds: Birds cover really long distances while migrating. Longest distancecovered is by Arctic Tern of approximately 17,600km, from north pole to south pole. There are many other birds considered long distance flyers. Look at the table below :

Table 1. **Variation in the extent of migration**

Species	Breeding area	Wintering area	Distance apart in miles	Kms
1. Arctic tern	Canada/Arctic	Antarctica	11000	17600
2. Pectoral sandpiper	Arctic	Argentina	9000	14400
3. Bobolink	Canada	South America	8000	12800
4. American Golden plover	Arctic Tundra	Argentina	10000	16000
5. Willow warbler	Siberia	Africa	8000	12800
6. Sooty shearwater	New Zealand	North Atlantic	6000-9000	9600-14400
7. Eastern golden plover	West Alaska, North, Siberia	Hawaii, Indonesia Australia, India	6000-8000 6000-8000	9600-12800 9600-12800
8. Great shearwater	Tristan a Cunha	North Europe	6000-8000	9600-12800
9. Buff breasted sandpiper	Arcitc Canada	Argentina and Uruguvay	6000-8000	9600-12800
10. Arctic warbler	North Europe and North Siberia	S. E. Asia	4000-7000	6400-11200
11. White stork	Europe	South Africa	4000-7000	6400-8000
12. Blue Cheeked bee-eater	N.India, West China	East Africa	4000-5000	6400-8000
13. Scarlet grossbeak	N. E. Europe	India, S. E. Asia	3000-6000	4800-9600
14. Ruft	Europe, Siberia	S. Africa, India, Sri Lanka	3000-6000	4800-9600
15. Black and white cuckoo	India	East and South East	3000-5000	4800-8000
16. Snow goose	Alaska	California Asia	2000-3000	3200-4800
17. Long tailed cuckoo	New Zealand	Africa Fiji	2000	3200
18. Pintail	Alaska, California	South America Hawaii	1000-4000	1600-6400

The black headed bunting travels about 6,500kms from south-eastern Europe to Bharatpur with a speed of 40 to 48 kmph. Majority of the birds migrate at night, they rest and forage during day time, waterfowl and shore birds- also fly at night hours, black poll warbler make non-stop, overwater flights for more than 3680 km lasting about 86 hours. The golden plover flies nonstop from Alaska to south America, covering 4000 kilometers. Greater shearwater fly across 12,800 kilometers from north Atlantic to south Atlantic. Blue geese fly 2720 kms in 60 hours. Most migratory birds can fly' about 800 kms that too nonstop.

Altitude at which migratory birds fly: Formerly, it was thought that birds while migrating travelled very high and with a very, fast speed. Recent knowledge, obtained by telescope, radar and radio telemetry has pointed out a great variety in flying altitude. Some birds fly at sea level, whereas, some fly very close to the height of Mount Everest.

Most birds fly less than 7,400 ft. above sea level. In the Himalayas, migrants fly between 800-1,600 ft. Strong fliers, such as ducks and geese, fly 4800 ft. to 8640 ft above sea level. In the Himalaya, migratory birds have been found at a height of 17,280 ft. Similarly blackpoll warbler, godwits and sand pipers, fly at 21,000, 20,000 and 13,000 ft. respectively. Blackpoll can fly where it is very cold, and at oxygen starved altitude of 21,000 ft. Himalayan expeditions found griffon vultures and lammergeier at 22,400 ft and Himalayan geese at an unbelievable height of 29,500 ft.

Speed of migratory birds: Generally birds follow the rule "fly low and slow." Most cruise speeds are in the 20-to-30-mph range. Ducks fly at the speed of about 47 mph to 60 mph or even faster, and it has been reported that a Peregrine Falcon can dive at speeds of 100 mph . Most birds can compete with an efficient automobile, like a car they can also cover 90 km in an hour. The speed of the migratory birds is measured using Doppler radar, it was found out that the speed ranged from 32 to 64 kmph in small song birds, while in larger birds, such as cranes speed varies from 40 to 96 kmph. Smaller perching birds can fly 32-59 kmph whereas,-falcons, ducks, and geese fly at the speed of 77-96 kmph, humming birds fly-32 kmph, and sandpipers fly 96' kmph. Most songbirds migrate at about 20-30 mph in still air .

Some famous Bird sanctuaries of India:

Keoladeo National Park: It is famous as one of Asia’s finest birding areas, with over 380 resident and migrant species, including the Common, Demoiselle and the rare Siberian Cranes. During the cool winter months it is also possible to see large Indian Pythons. Large congregations of ducks, geese, coots, pelicans and waders arrive in the winter. The park is known wintering site of the critically endangered Siberian Crane, and also serves as a wintering area for other globally threatened species such as the Greater Spotted Eagle and Imperial Eagle. The park has about 15 species of herons, ibis, cormorants, spoonbills and storks. Its difficult to name all the birds that come to Rajasthan are, a few are-

Indian Pitta, Godel oriole,Grayleg Geese,gargany Teal,Pintails,Common Teal, Gadwall,Common Pochard, Starling, ShovellersTufted ducks,Wigeon,Red crested Pochard,Common Shelduck,Marbel Teal,Falcated Teals, Siberian cranes.

Sultanpur Bird Sanctuary: Sultanpur bird sanctuary is home for several colorful winged migratory species, located at Gurgaon district of Haryana. Its small area comprising with shallow freshwater sultanpur lake, where hundreds of migratory bird species visit to feed every year. In Sultanpur National Park migratory birds such as Siberian Cranes, Greater Flamingo, Ruff, Black winged Stilt, Common Teal, Common Greenshank, Northern Pintail, Yellow Wagtail, White Wagtail, Northern Shoveler, Rosy Pelican, Gadwall, Wood Sandpiper, Spotted Sandpiper, Eurasian Wigeon, Black tailed Godwit, Spotted Redshank, Starling, Bluethroat and Long billed Pipit can be spotted.

Salim Ali Bird Sanctuary: This bird sanctuary is home to many varieties of local and migratory birds, situated in chorao Island along the river Mandovi in Goa. It is one of the smallest bird sanctuaries where flying Sparrows, Beautiful peafowl, Parrots, pelican, Indian giant squirral and other rare species of fauna can be spotted.Over 280 species of birds in the area have been listed including Crimson-throated Barbet, Sunbird, Fairy Blue bird and a few varieties of hornbill family.

Kumarakom Bird Sanctuary: also known as Vembanad bird sanctuary is situated in Kerala, near to the famous Vembanad lake. It offers a home to a large number of migratory birds like Flycatcher, Teal, Siberian Stork, Crane, Parrots and Wood Beetle. The main attractions are local birds like- waterfowl, cuckoo, owl, egret, heron, cormorant, moorhen, darter, and brahminy kite, as well as the migratory Siberian crane. Parrot, teal, lark, flycatcher, and other birds are seen here during their respective migratory seasons. Some of the migratory birds come from the Himalayas, and a few from Siberia.

Ranganthittu Bird Sanctuary: This bird sanctuary is situated near the banks of the Kaveri river in Karnataka. The exotic migratory birds like light Ibis, Egret, Partridge, Heron, River Tern, Snake Bird, stone Plougher are the attraction for the tourist.

Vedanthangal Bird Sanctuary : This bird sanctuary is one of the oldest bird sanctuary in India, situated in Tamil Nadu. The vedanthankal lake region attracted a variety of birdssuch as pintail, garganey, grey wagtail, blue-winged teal, common sandpiper.

Kaundinya Bird Sanctuary: It is situated near Chittor in Andhra Pradesh. It has two beautiful streams, which flow through the sanctuary. Bird sanctuary offers variety of migratory birds to its largest fresh water Kolleru Lake.The

Grey Pelicans, Rosy Pelicans, Pied Horn Bills, Painted Storks, Peacocks, Ducks, Love Birds, Budgerigars and Cockatiels .

Chilka Lake Bird Sanctuary: This is located near Puri in Orissa. It is a very large brackish water lake in Asia and famous for a rich variety of birds. The lake give shelter to over 160 species of birds in the peak migratory season. Birds from Caspian Sea, Lake Baikal, Aral Sea and other remote parts of Russia, Kirghiz steppes of Mongolia, Central and southeast Asia, Ladakh and Himalayas come here. The List is very long -lesser flamingos, Goliath heron, grey herons, purple herons, spoonbills, storks and black-headed ibis. Rare birds reported in the lake are Asiatic dowitchers ,Dalmatian pelican , Pallas's fish-eagles , the very rare migrant spoon-billed sandpiper and spot-billed pelican .The white-bellied sea eagle, pariah kite, brahminy kites, kestrel, marsh harriers, and the world's most widespread bird of prey, peregrine falcon, are among the raptors seen .

Many short-legged shorebirds are seen e.g plovers, the collared pratincole, ruff, dunlin, snipes and sandpipers. Larks, wagtails and lapwings

are also found . Other birds that are seen feeding in deeper water are the long legged avocets, stilts and godwits. Flocks of brahminy ducks, shovellers, pintails, gadwall, teals, pochards, geese and coots, are also seen.

Please note that the Irrawaddy dolphin (Orcaella brevirostris) is the flagship species of Chilika lake.

Mayani Bird Sanctuary: The Mayani bird sanctuary is known for its wide range of migratory birds . It is situated in Satara district of Maharashtra. Mayani Bird Sanctuary is located near Vaduj. Approximately 450 migratory birds were reported in 2007. Coot, Brahminy Ducks, Black Ibis, Painted storks, Common Spoon bills , northern shoveler are seen there. The nests of painted storks can be observed too. Flamingos are regular winter visitors to the place. One of the big attractions ofthis place is the Siberian cranes and the flamingos.

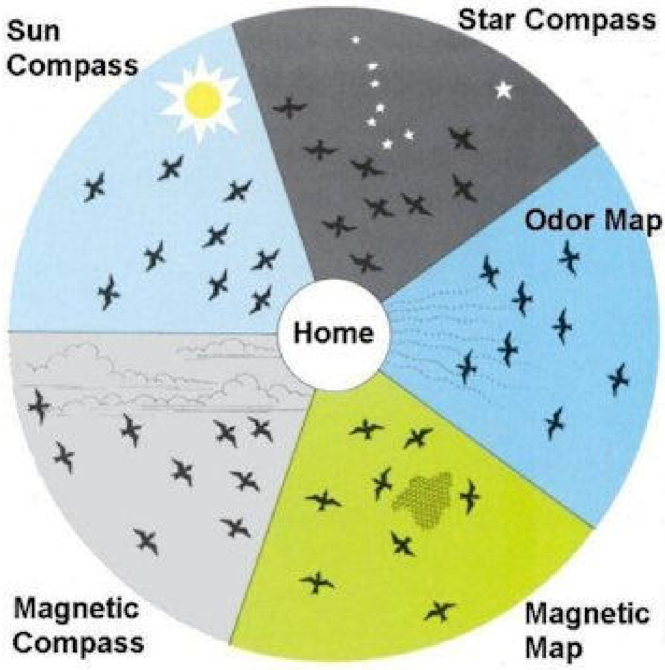
Nal Sarovar Bird Sanctuary: Nal Sarovar bird sanctuary comprising of a huge lake and marshes, near Ahmedabad, Gujarat. Nal Sarovar bird sanctuary is the largest wetland bird sanctuary in Gujarat . Birds that are easily seen there are - Flamingos, Pelicans, Spoonbills, Avocets, Coots, Pintails, small Cormorants, small Grebes and Shovellers . 250 types of migratory birds can be seen here. many of them come from .Siberia

Navigation by Birds:

Most of the birds are remarkable path finders. The knottiest problem in ornithology is how a bird finds its way home ?Bird navigation is complex and not fully understood. It is known that birds use a range of senses. To do this successfully, a bird must know where it is, it must know the direction of its goal, and it must be able to maintain its course or navigate in that direction. Many individually marked birds have been experimentally displaced thousands of kilometers into completely strange areas, and yet they have returned to their home nest sites. Homing ability is widespread in the animal kingdom, but it is perhaps best developed in birds.

1. It has been proposed that birds may have an, inborn, built in/ innate or instinctive programme to migrate, meaning that birds just know inherently that this is the time to migrate, where to migrate and how to migrate, that they only learn very little by watching conspecifics. How do birds determine their way and position themselves correctly remains a mystery for man.
2. Daytime migrants use their vision to steer by the sun and land marks, in some species, visual clues may be all that are required to guide birds on their migration travels. Birds following similar route every year only need to remember the different and prominent visual landmarks over which they fly viz. shores, islands, mountains, rivers, valleys, deserts and forests. Some migrants see ultraviolet and polarized light too .
3. It is believed that birds hear low frequency sounds (infrasonic) that emerge from distant waves and surf which help them in orientation. The other popular belief about how do birds find their way are that they have acute sense of hearing. Human ears will not pick up sound waves under ten to twenty cycles/see but birds can detect much lower levels therefore, while flying high they may hear a thunderstorm approaching, tides lashing at seashores and even rhythmic pulse of the ionosphere, birds may use this sense to gather information and orient themselves correctly.
4. How do night migrants find their way? Do they inspect the landscape by day and memorize it? Or they can see at night because even on moonless nights, the earth is by no means is featureless, rocks, trees, fields, rivers, and hills are clearly visible specially to dark adapted eyes. Night fliers take compass cues from moon and star positions.

5. Migrants can sense earth's magnetic field, probably in combination with gravity. A built in compass in animal's brain helps in finding ways, it is equivalent to our ideas of north, south, east and west. These compasses use magnetic field of earth and position of sun. The magnetic compass has been demonstrated in a number of vertebrate animals, it is assumed that animals have the ability to perceive the earth's magnetic field and thereby decide directions.



6. How do birds orient when they fly over sea? By judging wind and wave direction, by identifying islands, reefs, cloud formations over oceanic islands. They can even sense temperature and humidity differences in the air; colour, and turbidity differences in the great surface currents of the sea water, the presence or absence of organisms visible from the air such as dolphins, flying fishes, jelly fishes, and whales.

7. One of the navigation method a migrating bird could use in orienting itself with relation to the position of the sun. As we can do by looking at son and guessing the time of the day. Sun-compass orientationSun rises and sets rapidly, but is slow to change position around noon,first discovered by Gustav Kramer in 1951 working with starlings in orientation chambers.Solar navigationMany birds and animals such as honeybees can use the sun as a compass. Because the sun's position is always changing due to the Earth's rotation, animals need to adjust for the changing direction of the sun. They appear to have an internal clock that does this

8. Some birds can detect very minute differences in barometric pressure.

It has now been accepted that for navigation, birds use a variety of methods singly or in combination to effectively orient themselves to cover long distances. The method used by birds vary with species, age, experience, location, weather and season.

9.4 Definition of social behaviour, properties and advantages of social grouping, social groups of monkeys and bees

9.4.1 Definition of social behaviour, properties and advantages of social grouping

9.4.2 Social groups of monkeys and bees.

9.4.1 Definition of social behaviour, properties and advantages of social grouping

Society/social group : A group of animals of all age sex classes who live close, interact and cooperate with each other and share the same geographical territory.

social behaviour: Social behaviour is defined as interactions among individuals, normally within the same species, that are usually beneficial to one or more of the individuals. It is believed that social behaviour evolved because it was beneficial to those who engaged in it, which means that these individuals were more likely to survive and reproduce better.

Properties of a social group:

1. Cohesion- members of the group stay in close vicinity.

2. Individuals of all age sex classes are present at any given time of the year: Old, adult, subadult, juvenile and infants(age), males and females.

3. There must be a form of communication between them: Members of a group communicate with each other verbal and visual.

4. Division of labour/work: Members in a social group perform different functions. Adult males lead the group to water, food, and to safe shelter. Other males protect group from predators , adult females bear babies, juveniles help females, babies practice wrestling in form of play.

5. Permanency in group membership: The related females make the core of a social group, the males come and go.
6. Altruism : Members in a social group are related to each other and show sacrifice for each other.

Advantages of being social:

(1) Antipredation: More members in a group improved detection of predators - with more eyes, ears, there is an increased chance that one or more individuals will detect a predator before the others and be able to warn rest of the group e.g. in a group of deer or monkeys, one or two individuals give alarm calls at the sight of .approaching predator and the rest of the group members take advantage of it, in a flock of birds alarm calls are given by few individuals and the rest get the advantage.

Animals also show "guard behaviour" in which one or a few individuals assume the role of watching for the entire groups, thus freeing the others almost completely from the job of vigilance e.g. adult males of hanuman langur occupy the highest canopy and remain vigilant for intruding members of all-male groups and/or for predators .

Mutual vigilance has also been observed among the members of different species. Social animals living in the same habitat respond to the alarm calls given by the members of other species e.g. baboons, zebras, gazelles often forage together, and each species responds to warning signals of each other.

Erratic flight and explosive scattering, fleeing along an unpredictable path is a common defensive tactic in social or herding animals. Simultaneous erratic scattering of many individuals is likely to be more confusing to a predator than flight by a single individual. Sudden, explosive movement -startles and confuses the predator.

Mobbing , running away or fleeing is being the most commonly used anti predatory strategy among animals yet there are examples when adult animals, generally males mob a predator or form a defensive screen to scare it away. Soldiers or workers of social insects defend colonies by collective attack. Muskox of North America when attacked by wolves, adult female muskoxen form a defensive ring around their calves.

(2) **Feeding efficiency and information sharing :** It is easier for a group of animals to catch a prey instead of catching it alone. Cooperative foraging is beneficial e.g. for a .group of monkeys it is easier to locate a bonanza of fruits. Early in the morning, members of a monkey group will spread and roam around in search of food and when one individual locates the food it communicates vocally to other members of the group who get the benefit of this information.

By cooperative hunting carnivores like wild dogs and wolves hunt big animals like elk and sambhar. Also mutual vigilance for predators allow each individual to spend more time foraging, without increasing vulnerability to predators. The animals of a group can leave their young ones with other group members and go foraging e.g. the pups of wolves are often attended by few adults in den, while other peck members go out hunting. In a group of langurs, the related adult females temporarily take away the infant from mother to enable her to forage, this behaviour is called aunt behaviour.

(3) **Facilitation of reproduction**: Group living improves reproductive success. For example, in solitary animals like rhino and orangutans it is difficult to find a mate,they have to cover large areas in forest, spend time and energy but it may be easier to find each other in a large social group. In a group, watching others courting and mating initiates sexual behaviour in other members also. Communal breeding, nesting in beneficial to animals. This is exhibited by about 13% of bird species.

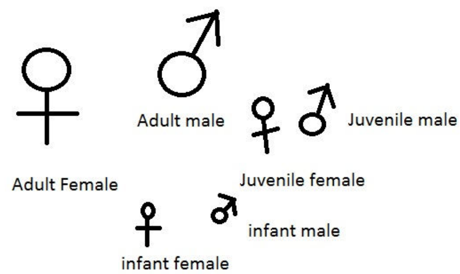
9.4.2 Social groups of monkeys and bees

Monkeys -

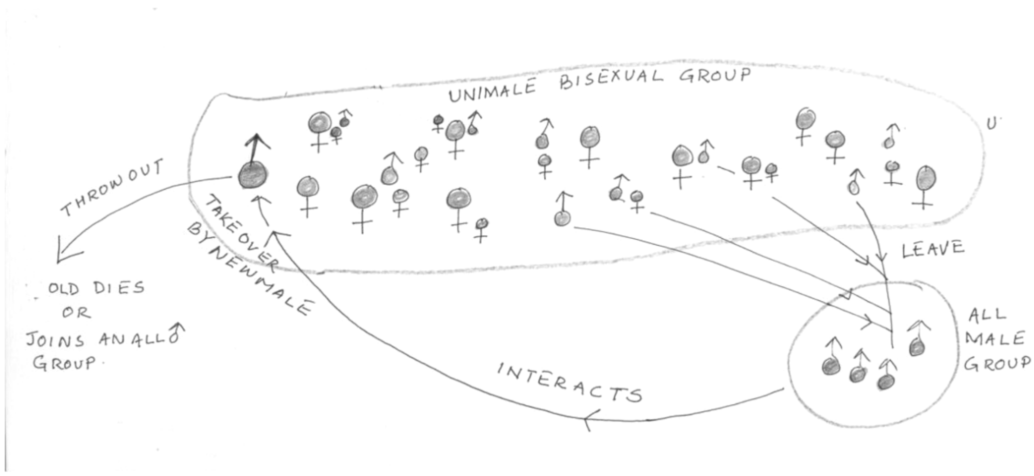
1. **Solitary, except for mother infant pair**. Examples: Orangutan, slow loris, slender loris, aye - aye . These primates are forest dwellers, smaller in size, arboreal. Males are usually found solitary but they can be seen in following combinations as well :male and female; male and female with infants; female with infants; 1-2 subadults. Since they are mostly alone, their anti predatory tactic is concealment. They remain in one home range and may defends It actively. The sexual partners only meet for reproduction.

2. **Monogamous adult-pairs with recent off springsor nuclear families:** Examples : Indri, marmoset, gibbon, dusky titi , tree shrews, lemur and night monkey . Nowhere among the social primates are females

accorded more permanently privileged positions than among the monogamous species. Gibbons are lesser apes found in far east countries and India. Their groups include 4-8 individuals consisting of an adult male and adult female and one baby. Male-female bonding is permanent and lasts lifelong. If the partner disappears then is replaced. In such groups usually there is not much difference in the body size of male and female. They have equal dominance. All monogamous groups have definite territory which is defended actively, both partners sing "songs". Dueting is sympatric of monogamy . Monogamous primates are usually smaller in size; they feed on high protein diet viz., insects, new leaves and ripe fruits. The parental investment is equal.



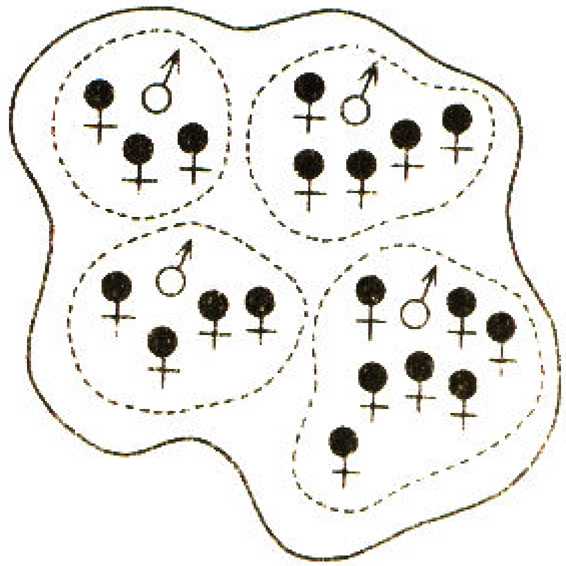
3. **single male with bonded femalesgroups** or unimale bisexual groups: Examples - Hanuman langurs, Howlers, red tail monkey, blue monkey. Typically they live in group of having 20 to 100 individuals; there will be just one adult, fully grown, big sized dominant male popularly designated as "overlord" or "resident. male"; rest of the groupis formed of adult females, subadult females, male-female juveniles andinfants. Growing males either leave their natal group or are chased away to form **all male** groups. Adult male is the leader and coordinator of group activity, he initiates and determines the direction of group movement and activities like where to go, when to feed, where to sleep. In unimale bisexual groups of hanuman langurs the adult male alone defends the territory, herds females away from intruding males of all male group, generally he alone indulges in fights . In such groups males are much larger in



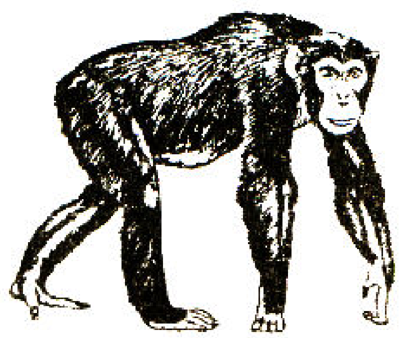
size then females. The male is dominant over all the members of his group , male parental investment is almost nil. The anti predatory strategy is climbing up the tree branches with all agility. Changing of overlord in a unimale bisexual group is of common occurrence. During interaction between adult male and males of all male group, one of the adult males of all male group would chase the resident adult male and take possession of harem, this is known as "takeover".

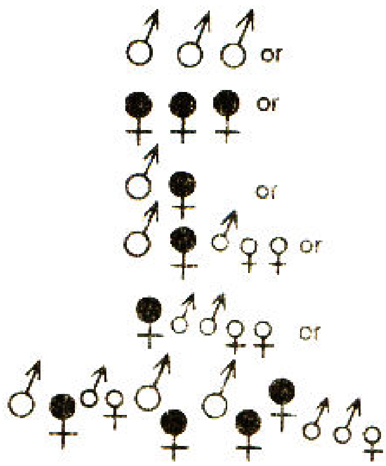
4. **Many males with many females and off springs or multi male bisexual groups:** Examples: Rhesus, gorilla, baboon, spider monkey, woolly monkey, squirrel monkey form this kind of groups .Typically there are 3-8 adult big males in such a group, each of which has 5-7 bonded adult females who remain with their infants. In a way , there are many small units living together thus forming a big group. Multi male bisexual groups are generally larger than other social groups. One such group can have up to 180 or even more individuals.

   One of the reasons of origin of multi male bisexual groups is linked to their terrestrial nature. Millions of years ago when competition increased in trees, few of the primate species left the trees and came to the ground, where they became more vulnerable to predators; these primates increased the number of males, they increased the overall number of members in a group and they increased in body size as well, in addition, they developed powerful jaws and became more aggressive, because their anti predatorystrategy was "fight the predator,"

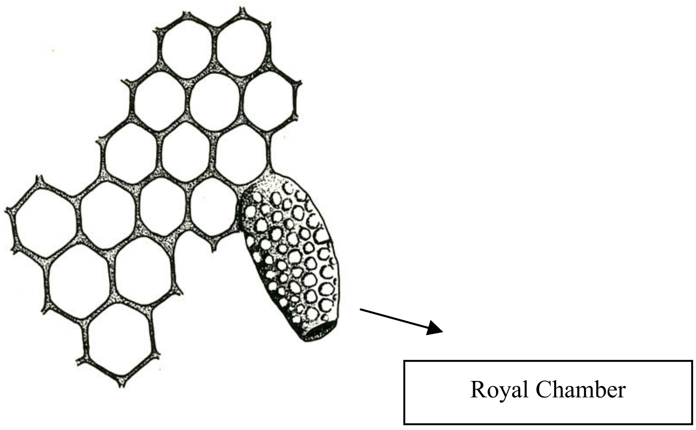


5. **Diffused social parties:** Examples: Chimpanzee,they are found in Africa. Chimps form diffused social parties. They follow no strict social organization. They may be seen in bands of males, groups of females, with or-without off spring, or form large troops of males and females with young, they may also be seen wandering alone.





Social group of Bees:An average of 10,000 bees live in a hive. They follow a strict cast system. There is only one big sized fertile female called "**The queen** ".Only she can lay eggs. **Drones** are males. There may be several hundred in a hive. Their function is to fertilise the queen, then thousands of **Workers** which are sterile females. Workers do all the work of building the combs, collecting and storing nectar and pollen, feeding the larvae and cleaning the hive. The workers build two types of wax cell, differing in size or shape. The biggest is royal chamber, then smaller then it are drone cells, and smallest ones are worker cells.



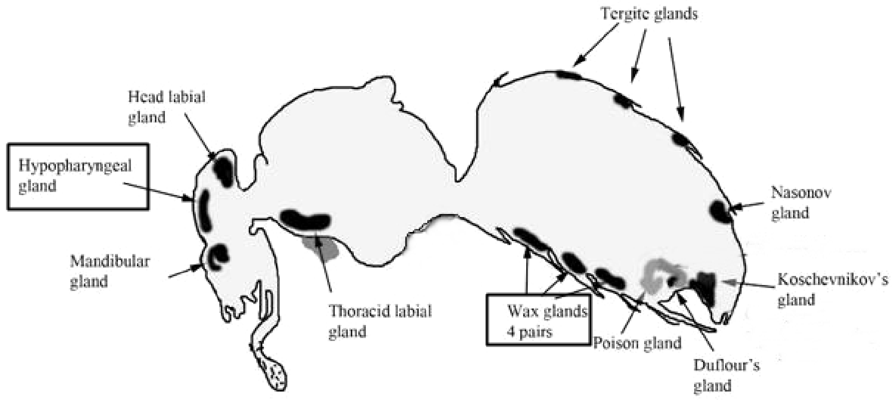
The queen lays eggs , the workers called midwives, collect eggs from royal chamber and put them in different cells, according to the need of the hive. The eggs hatch, workers look after them, and feed drones and workers "bee bread" which is poor in nourishment. If the new queen has to be made, then those are fed "Royal jelly" till they are larvae . First get familiar with following terms:

Honey is a sweet food made by bees using nectar from flowers. Honey contains about 80% sugars, mainlyglucose and fructose Bees swallow them , nectar, pollen are partially digested in stomach, mixed with saliva, and regurgitated (vomited) out of the body, air dries this partially and make it thick, Workers put them in hive cells and seal the cap, this is bees staple food. Bees work very hard to produce honey . To produce about 500 g of honey, honey bees have to travel the equivalent of three times around the world . Worker bees need to visit around 2 million flowers to produce a pound of honey.

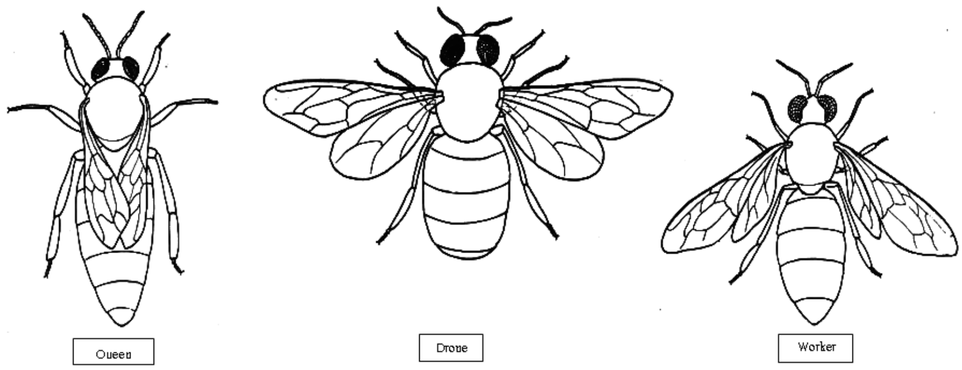
Bee Bread: A mixture of Honey(nectar + digestive enzymes= regurgitated, thickened due to evaporation) and pollen, deposited in the cells of a comb to be used as food by workers and drones.

Royal Jelly :Secreted from hypopharyngeal glands, located on head. Constituents of royal jelly are water, protein, sugars, lipids and mineral salts .The nutritionally powerful, milky substance or "pollen mush" that turns an ordinary bee into a Queen Bee is made up of digested pollen , honey , nectar and mixed with a chemical secreted from a gland in a nursing bee's head. This "milk" is fed only to the larvae chosen to become a queen . The queen grows one and a half times larger than the ordinary bee, and is capable of laying up to two thousand eggs a day. The Queen Bee lives forty times longer than the bees on a regular diet.

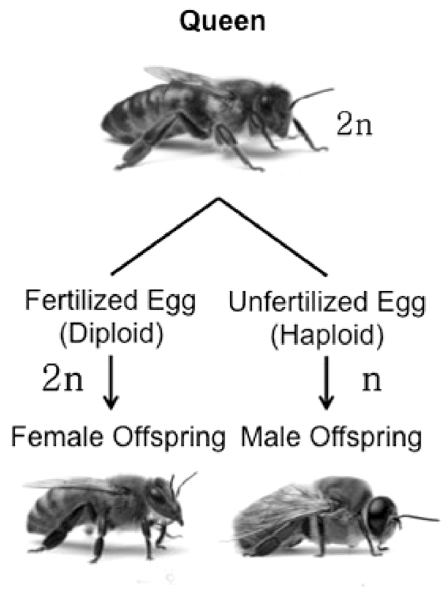
Beeswax: Secreted from the glands on abdominal segments 4-7, beeswax is used by the honey bees to build honey comb. It is secreted on sternal wax plates which are located on the ventral side of abdomen, from where it is removed as flakes and chewed with mandibles, softening it with the secretion of mandibular glands, used by the bees to build honey comb.



The difference in diet causes the workers to be sterile and the queen to be fertile.



Honey bee life cycle has four main distinct stages - egg, larva, pupa and adult. The colonies of bees consist of three castes - Queen(fertile,2n) lay eggs, worker non-egg producing(sterile, 2n) and drones(males, fertile, 2n) for mating purposes.



Developmental time for honey bees: The life stages of a honeybee are egg, larva, pupa and adult. The total developmental time for a Queenis 16 days, 21 days for worker and approximately 24 days for drone. Four distinct honey bee life cycle stages can be summarized as following.

Life Cycle: The **queen** mates only once in her life time and stores the sperms received from the drone in a sperm sac in her abdomen for many years .She remains in royal chamber, worker bees feed her, clean her, midwife workers, collect eggs and put them in cells. When the store of sperms is used up she continues to lay eggs but they are all unfertilized and become drones. By this time, one of her daughters has been reared as a queen and is ready to take over the egg-laying.

Drones. The drones, who live for about four to five weeks and do not work inside the hive, are fed by the workers or help themselves from the store of pollen and nectar in the combs. Their function is to fertilize a new queen. Once this task is over, they are not allowed in the hive, soon they die.

Workers. The workers are female bees whose reproductive organs do not function. Among many other tasks they collect food, water from outside the hive and store it, make the wax cells and feed the developing larvae. Cleans cells and warm the brood nest , produces wax and constructs comb, guard the hive entrance and ventilate the hive.

Life of a queen. queen leaves the hive for nuptial flight , she is pursued by drones, one of them catches the queen and mates with her, depositing in her vagina thousands of sperms which eventually find their way into her sperm sac. She returns to the hive, and once reaches the royal chamber start laying eggs.

Now you need to know a very amazing phenomenon found in bees called Eusociality. In animal kingdom, if an individual makes a sacrifice for the benefit of other group member it's called **Altruism .** In bee hive, thousands of females(remember-sterile females make workers? And they remain sterile, as they feed on low nourished bee bread?) sacrifice their reproductive privilege for the sake of queen.

Eusociality: Now you already know what is social behaviour and what is society. There is a Degrees of Sociality**:**

a. Solitary: exhibit no social behaviors e.g most arthropods.

b. Sub social: adults care for their own nymphs or larvae Monarch Butterflies.

c. Communal: members of the same generation use the same nest without cooperating in brood care.

d. Eusocial : Definition of Eusociality was developed by E.O. Wilson. When members of the same generation in a social group sacrifice their own reproduction(reproductive fitness) and use the same nest and cooperate in brood care it is called Eusociality is especially prominent among bees, ants, and wasps, W.D. Hamilton was the leading scientist to explain how altruistic behaviour can be beneficial in terms of evolution. Sacrifice/altruism is considered the height or ultimate of sociality. Honey bees are classical example of this phenomenon. Thousands of females remain sterile, do not produce progeny, instead help queen alone to produce eggs. Sterile females look after the larvae and queen. If you have understood Eusociality, it leads us to the next part ie Sociobiology.

9.5 Sociobiology – Proximate and Ultimate causations, Darwinian fitness, individual fitness, kin selection, group selection, cooperation, reciprocation, altruism

9.5.1 Sociobiology – Proximate and Ultimate causations

Sociobiology is defined as "Systematic study of the evolutionary basis of all forms of social behaviour in all kinds of organisms". Sociobiology is a field of scientific study which is based on the assumption that social behaviour has resulted from evolution , Socio-biologists are interested in "how behaviour can be explained logically as a result of selective pressures in the history of a species" . This branch of science is a combination of variety of subjects-ethology, anthropology, evolution, zoology and population genetics .Subject can be traced back to late1940s when John Paul Scott (1926 -1986),USA coined the word "sociobiology" at a 1946 conference on genetics and social behaviour. But the concept didn't gain much recognition until 1975 with the publication of **Edward O. Wilson's book, Sociobiology: The New Synthesis**. Wilson is rightly know as father of sociobiology.

You already know from previous paragraphs that many animals form groups to enhance their foraging success and better protection against predators. This group of individuals of the same species that is organized in a cooperative manner extending beyond sexual and parental behaviour is called a **social group**. And the study of the biological basis of social behaviour is called sociobiology. Sociobiology has provided a whole new way of looking at behaviour to the scientists. It is promising a greater understanding of human behaviour. It is a relatively new branch of ethology. Hamilton (1964) ,Williams (1966), Trivers (1972), Sherman (1977) , Wage (1979) , Barash (1979)and Warren (1980) have been the pillars of sociobiology.

As mentioned earlier, Sociobiology found its recognition in the book written by **Wilson** in **1975**. Ever since sociobiology has found its bearings, it has influenced interpretation of animal's behaviour. Scientists have reinterpreted the old data in light of its evolutionary significance. Sociobiologists believe that same principles that explain animal's behaviour can be applied to interpret social behaviour of human beings. This belief has given rise to yet another interesting branch which deals with human ethology. Actually it forms a bridge between ethology and psychology.

All students of animals behaviour ask the question" Why does an animal perform a particular behaviour or why do animals eat or why do birds and fish migrate? There are two different ways of answering it. Study of sociobiology employs evolution to interpret the basic patterns of animals social behaviour and provides two ways of interpreting behaviour:

1.Proximate and 2.Ultimate

For feeding the **proximate answer** given by an **ethologist or ecologist** to it would be because:

(i) Their stomach is empty, their energy has gone down ,

(ii) less blood glucose in blood stimulates hunger centre in hypothalamus.

(iii) Animal searches for food, eats food, satiety centre of hypothalamus is stimulated, (iv) blood glucose level goes up and animal stops eating.

A sociobiological explanation would be;

(i) Hungry animal, having low glucose, less energy will not have a normal growth

(ii) it must eat to require essential building elements

(iii) Build a healthy body, attain sexual maturity, breed and produce babies for the benefit of species.

Why do birds migrate**? Proximate(immediate)** reason would be:

(i) they undergo hormonal changes due to change in temperature, rainfall or humidity.

(ii) as the day length increases it stimulates the hypothalamus, that in turn influences their body physiology to initiate migration.

(iii) they accumulate body fat for **migratory restlessness** and consequently they migrate.

Whereas, asociobiologist will explain it using **ultimate (evolutionary) interpretation**:

(i) Animals must escape harsh climate to survive and breed for perpetuation of species. Scarcity of food causes animals to explore other areas with more food, if they get sufficient food, their survival is better, if this is so, then they can live, attain maturity, breed and leave progeny , therefore, migration becomes important from the point of view of evolution.

The sociobiologist looks into questions like " what is the evolutionary significance of a behaviour?" " what is the adaptive significance of the behaviour? " are animals behaving in a way that maximizes their fitness?" The proximate reasons help to give ultimate answers. The explanation of any behaviour is more satisfying when it is explained both ways.

9.5.2 Reproductive success ,Darwinian fitness, Individual fitness, Kin selection, Group selection

Reproductive success: Is measured in terms of number of reproductively mature progeny an animal leaves. Imagine a pair "A"(male and female, say F1) , they reproduce and produce four babies(F2), all these babies survive and attain sexual maturity, mate and produce a fertile progeny(F3), then the parents (F1)are said to be reproductively successful (in terms of evolution).

Opposite to this, a pair" B" (F1) reproduces , produces four babies (F2), out of that two die, and only two reproduce to produce babies (F3). Pair "A" is reproductively more successful in comparison to pair "B". It is measured in terms of **fitness.**

Fitness: It is a measure of **evolutionary success** that applies to reproduction and leaving of fertile progeny. He/she who leaves maximum progeny (that gets mature and reproduces is considered the fittest in terms of evolution).

Darwin proposed that each individual behaves in such a manner that it must maximize its own fitness. The sociobiologists have taken this idea further ahead, according to them " yes , all animals behave to maximize their own fitness, but they also behave to increase the fitness of a relative".It is a measure of evolutionary success that applies to genes, traits, individuals, or populations.

According to Darwin every individual is concerned only about its own survival but modern theory of sociobiology says that there are different levels of survival that grows up to the level of population :

(i) if it relates to only one individual it is called **Individual orPersonal or Darwinian or classical fitness**,

(ii) if it relates to own and off springs it is called **Inclusive fitness**.

(iii) If it relates to own , off springs and relatives then it is known as **kin selection .** Imagine a group of individuals linked by kinship within a population. These blood relatives cooperate one another in a way that increase the average genetic fitness of the members of the group as a whole, even when this behaviour reduces the individual fitness of certain members of the group. The members may live together or be scattered throughout the population. The essential conditions is that they jointly behave in a way that benefits the group as a whole, while remaining in relatively close contact with the remainder of the population. This enhancement of kin- welfare in a population is kin selection. Kin selection is especially important in that it suggests a biological basis for altruism.

(iv) And finally if it relates to own , off spring, relatives, group members and members of other population(same species) even distantly related or unrelated it is called **group selection.** All in all, they work towards perpetuation of their species. From here we go to the next step ie do animals cooperate or reciprocate or sacrifice? If yes, why? And what is the benefit?

9.5.3 cooperation, reciprocation, altruism

There are broadly four behaviours that need to be explained: Selfish, cooperation, altruism and spite. Look at the small table given below showing interaction between two actor(who performs) and Recipient(who watches or receives) :

Type	Actor	Recipient	example
Selfish	+ (benefit)	- (cost)	(rare)
Cooperation	+ (benefit)	+ (benefit)	(very common) Help Chasing predator away
Altruistic	- (cost)	+ (benefit)	(common) Sharing food with a relative
Spiteful	- (cost)	- (cost)	(occasional) Fighting and aggression

Cooperation/ reciprocation : Related animals help each other at the time of need. In Cooperation both gain simultaneously. **Cooperative brood care -** is seen in birds and monkeys. Trumpeter swans and Canada geese look after babies collectively .**Cooperative hunting -** is common in wolves, wild dogs, crocodiles, seals, walruses and many such predatory animals. Jackals get together and encircle a gazelle and her fawn , cooperation between them leads to separation of mother leads to easy catch of fawn . Lion social groups are formed of related females, they exhibit **cooperative** behaviour , females cooperate (i)in hunting and (ii) during defence, and in (iii) rearing of cubs .**Cooperative defence** - is also common among animals. Birds of the same flock mob the snake , moneys of the same group face the predator collectively. Musk oxen form a defensive ring around their calves , to prevent them from wolves . Male lions **cooperate** in attempts to acquire or defend a pride of female from other males. **Cooperative nest building -** many species of ants show this behaviour .**Communal Nesting-** bird species at sea shore nest communally, with several females raising young in the same nest. Ostrich show communal breeding, where one bird looks after the eggs , while other ostrich patrols the area . **Helpers-at-the-Nest** - about 100 species of birds have been identified as nest helpers. Florida scrub generally has a related net helper .

Animals also show **Reciprocal / reciprocity** (Trivers, 1971) means “you help me today , I will help you later whenever you need “ for example, one person saves a drowning person in exchange for the promise that his altruistic act will be repaid if the circumstances are reversed at some time in the future. It's like **“ you scratch my back today and I will scratch your”.** Unless the altruist get enough back in return for its cost, such behaviour will not evolve.The trading of altruistic acts by individuals at different times. These considerations suggest that reciprocity is most likely to take place among closely integrated social species in which the opportunities for reciprocity and individual recognition would be greatest. Reciprocation can be done at some other time. Dolphins help the sick to come to the surface to breath. Next time when the helping dolphin gets sick it will get the same help from other group members . Baboons, langurs, zebras, birds look after babies of related individual of their groups . **Relatives are involved in care of young / allo parenting** . Among birds **helpers-at-the-nest are found in** eg **Florida Scrub Jay, green wood hoopoes, white-fronted bee-eaters, babblers, and Mexican Scrub Jay .** In elephants, wolves, dwarf mongoose, monkeys, lions the related females , called **aunts** help in feeding the baby , related elephants help each other in acts like while mother drinks at a water hole, the aunt guards the young . As mentioned earlier, Hanuman langur of India lives in unimale- bisexual groups . The core of the group is formed of related females. Related females help each other in rearing babies. Aunt behaviour is pronounced among langurs

Altruism is a well-documented animal behaviour, which appears most obviously in kin relationships but may also be evident amongst wider social groups, in which an animal sacrifices its own well-being for the benefit of another animal. Individual sacrifices reproductive chance /success or sacrifices scarce food, water, shelter for the benefit of other related animals in the group. Altruism in a social group depend on the **“degree of relatedness”** denoted by **“ r ”**. Higher the r value between two individuals the more genes in common . Degree of relatedness *r* (= fraction of genes identical by descent) for various relatives in a random-mating population is: Parent-offspring 1/2 ; Full siblings 1/2 ; Half siblings 1/4 ;Uncle/Aunt - Nephew/Niece 1/4; First cousins 1/8 and so on. You may be wondering or may be uncomfortable with the notion of animals doing their **arithmetic** and then **behaving accordingly**. Recall that such computations are not required of the animals themselves. Rather, animals have been selected for behaving in certain ways under certain circumstances. **The arithmetic is done by natural selection**. Individuals who behaved in a way that produced maximum return (measured in units of fitness) were positively selected. Therefore the species came to be composed of individuals each of whom behaved as though it knew its arithmetic.

"Behaviour that reduces the Darwinian or individual or classical or personal fitness of performing individual while increasing that of the recipient is called altruistic behaviour." As stated earlier, Darwin had imagined that individuals behaved for their benefit only but **Lewontin** in **1970** observed for the first time **in Australia** that related **rabbits** helped each other .Sometimes one rabbit sacrificed food or shelter for another related rabbit. After this example if you read the definition again it gets a meaning. Reduction of personal reproduction in order to favour the reproduction of other related animals is called altruism.

(1) Altruism is more common among closely related than among distantly related individual;

(2) Altruism is more common among species with relatively little dispersal that therefore are more likely to share kinship ties with their neighbours; and

(3) Species exhibiting altruism are relatively more likely to discriminate against outsiders (non relatives) and to recognize insiders as individuals.

The alarm calls of birds: When one of the members of a flock of small birds foraging through the forest spots a hawk sailing through the trees, it may utter a thin whistled call. This alerts the other birds to danger, and the flock may dash to the cover of a thick hedge or tree. Alarm calls of similar structure are given in similar situations by many social birds and mammals. Florida Scrub gives a distinct alarm call towards an approaching snake . The caller risks detection by a dangerous enemy in order to help other group members that have not yet seen the predator. Why doesn't animal that first spots danger slip off quietly instead of drawing attention to itself ? This seems safer than giving an alarm call, and it might have the additional benefit of eliminating a competitor's genes if the predator were to catch an unsuspecting flock member. By doing this, the animal giving alarm call is saving a huge gene pool it shares with other relatives (group selection).

Food Sharing : No behaviour is more clearly altruistic than sharing of food. The social insects have carried food sharing to a high level. In ants, the "communalstomach," together with a specially modified gizzard, forms a complex storage and pumping system that functions in exchange of liquid food between members of the same colony (Eisner, 1957). Altruistic food sharingamong African wild dogs, where it permits some individuals to remain at the dens with the cubs while others hunt (Kuhme, 1965). The donors carry fresh meat directly to the recipients or else regurgitate it in front of them. Occasionally a mother dog will allow other adults to suckle milk. **Confuse the predator :**Related animals try this tactic very often. A group of deer is formed of related females . when a cheetah starts chasing an individual ,the closely related female keeps a close check, she knows soon my sister will be tired of running and will be killed. She also knows that cheetah is the fastest running land animal . So to help her sister , she goes closer to cheetah, cheetah gets confused and leaves the first one and starts running after this fresh animal who Is not so tired, whereas, cheetah is already quite tired . In the mean time the first deer escapes to a safe distance. This second deer, also runs away. But a great risk is involved. There are chances that while saving the sister , the second deer is caught. This can also cost her life. This is a great act of altruism.

9.6 Summary

This is a big unit, covering what part of human brain controls which behaviour ; how a tiny net work of inter connected nuclei form an important limbic system necessary to maintain our emotional equilibrium; hypothalamus- though small but controls hunger, thirst, maternal and sexual behaviours. In Brain stem, reticular formation is responsible for waking and sleep mechanism, work in close association with biological clock. Clocks can be daily, annual and lunar, this knowledge is being used for benefit of human called chronobiology; a good example of annual biological clock is bird migration; how do birds find their is still under extensive experimentation. Birds navigate using earth's magnetic field, location of sun , moon and stars, they also see land marks while flying.

You have read in this unit what is a society, social group and social behaviour, to be called as social group certain properties are prescribed- cohesion, communication, division of work and altruism .What are the advantages of living in a social group? More eyes-more ears, good chances of reproduction, better ability to fight predator. Monkeys live in five kinds of social groups- solitary, nuclear, one male-many females, many males-many females and diffused parties. Honey bees have cast system, there is one queen, few drones and thousands of workers. Workers are sterile females, they sacrifice their reproductive rights in favour of queen, who alone breeds. This is called eusociality.

At the end you studied about a new branch of zoology called Sociobiology. This explains all behaviours under two causations - Proximate(immediate benefit to animal) and Ultimate (evolutionary benefit to species). Evolutionary success of all living organisms is calculated by how successful that animal was to multiply its genes, and could produce progeny which in turn reaches maturity and leave progeny . According to Darwin every individual is concerned only about its own survival but modern theory of sociobiology says that there are different levels of survival that grows up to the level of population : if it relates to only one individual it is called Individual or Personal or Darwinian or classical fitness, if it relates to own and off springs it is called Inclusive fitness If it relates to own , off springs and relatives then it is known as kin selection . And finally if it relates to own , off spring, relatives, group members and members of other population (same species) in same geographic area even distantly related or unrelated it is called group selection**.** Do animals cooperate, reciprocate favours and sacrifice their resources? Yes, they do.

9.6 Glossary

- **Cerebral cortex**: Out lining of cerebrum, made up of grey matter
- **Cerebrum** : Biggest part of brain, is made up of white matter
- **Cerebral lobes**: Cerebrum has four lobes frontal, parietal, occipital and temporal
- **Hemispheres** :Whole of cerebrum is divided into two hemispheres-left and right
- **Corpus callosum**: corpus callosum joins the two hemispheres
- **Cerebellum:** small part close to brain stem, coordinates motor actions
- **Brain stem**: has reticular formations and reflex centre for breathing
- **Hypothalamus:** tiny structure near pituitary, has centres for eating, drinking, maternal and sexual behaviour
- **Limbic system**: Cluster of nuclei deep into brain, function together to main emotional equilibrium

- **Reticular formation:** Has net work of nuclei for sleep and wake
- **Daily cycles** (**Circadian**) :to cope up with day and night
- **Annual cycles**(**Circannual**) :to cope up with changing of the seasons
- **Lunar cycles** (**Circalunar**) :to cope up with changing phases of moon and
- **Tidal cycles** (**Circatidal**): related to the tides
- **Entrainment/zeitgeber** ("time giver" in German): setting and resetting of biological
- **Ultradian** (fast oscillating): Completed in few seconds, few minutes, few hours, half day.
- **Circadian**: completed in approximately 24 hours
- **Infradian** (slow oscillating) :Completed in half week, few weeks, few months, few years.

  By another classification body rhythms are divided into following four types :
- **Circaseptan:** A rhythm with a period of about 7 (± 3) days is seen in cell multiplication.
- **Circadiseptan:** A rhythm with a period of about 14 (± 3) days.
- **Circavigintan:** A rhythm with a period of about 20 (± 3 days). **Circatrigintan:** A rhythm with a period of about 30 (±5) days. Includes, in mature women during the time of ovarian activity, the menstrual cycle.
- **Migration**: An annual two-way movement between breeding site(their home) and feeding site (their temporary home).Its a pendulum movement between these two sites.
- **Zugunruhe/migratory restlessness :** Prior to migration birds eat more and store fat. As the time approaches they start hopping here and there.
- **Types of Migration**: There are six types of migration : (1) Daily/Local ,(2) Seasonal (3) Cyclic (4) Latitudinal (5) Altitudinal (6) Longitudinal

- **Society/social group :** A group of animals of all age sex classes who live close, interact and cooperate with each other and share the same geographical territory.
- **Altruism** : Members in a social group are related to each other and show sacrifice for each other.
- **Nuclear family**: One male, one female ,recent off springs
- **One male many female groups**: Harem system, where one male controls many females , juveniles and infants.
- **Many male many female groups:** One male with few females and their babies make a unit, many such units live together
- **Royal Jelly**: Honey plus pollen plus secretions of hypopharyngeal gland make extra nutritive food, give to queen
- **Bee bread:** Honey and pollen given to workers and drones
- **Honey** : Nectar and pollen eaten by bee, mixed with digestive juices then vomited back, gets thick due to evaporation
- **Eusocial** : worker bees are sterile females as they feed on bee bread low in nourishment, they sacrifice their reproductive rights in favour of queen, who alone breeds.
Proximate: immediate benefit to animal
- **Ultimate** : evolutionary benefit to species
- **Fitness** : It is a measure of evolutionary success that applies to reproduction and leaving of fertile progeny.
- **Individual or Personal or Darwinian or classical fitness** : if it relates to only one individual **Inclusive fitness** : if it relates to own and off springs it is called
- **Kin selection** : if it relates to own , off springs and relatives
- **Group selection:** if it relates to own , off spring, relatives, group members and members of other population (same species)

9.7 Self-Learning Exercise

1 Triune brain concept was proposed by ....

2 Midbarin is also named as................

3 Broca area controls..........................

4 ....works as central switch board in brain

5 coordination of muscular activities takes place in..........

6 James Papez is known for its discovery of ....

7 Amagdala controls aggression and fear-T/F

8 Sensory cortex is located in parietal lobe T/F

9 Animals active only in the morning are called .....

10 Entrainment means biological clock T/F

11 Franz Halberg, is known as "the father of ....

12 Ultradian is fast oscillating clock T/F

13 Circatrigintan: A rhythm with a period of about 30 (±5) days

14 "Master circadian clock" that regulates our clock in our bodies is found in basal ganglion T/F

15 Zugunruhe is known as ....

16 Migration that takes place from east to west is called..........

17 Salim Ali bird sanctuary is located in ......

18 Altruism does not have any evolutionary significance T/F

19 langurs make........................... groups

20 Worker bees are sterile males T/F

21 Bees make wax from....................

22 EO Wilson is known for his work in ....

23 Altruism is where actor bears a cost and receiver is benefitted T/F

24 Degree of relatedness mean percentage of common genes T/F

25 A measure of evolutionary success that applies to reproduction and leaving of fertile progeny is called......................

Section -A (Very Short Answer Type)

1 Name major structures in brain

2 Explain three brain concept

3 Write functions of frontal lobe

4 Name two speech centres and their location in brain

5 What are the functions of occipital lobe

6 Write location and function of cerebellum

7 Give examples of circadian cycle

8 What do you understand byMatutinal and Vespertine animals.

9 What is Chronopharmacology?

10 Define migration and its type

11 Diferentiate between latitudinal and longitudinal migrations

12 Write briefly on keoladeo national Park

13 Define society, social group and sociobiology

14 What is a take over in langur group?

15 What is eusociality?

16. Define altruism and cooperation.

Section -B (Short Answer Type)

1. Write functions of frontal and parietal lobes.

2 Write a note on hypothalamus

3 Explain different types of biological clocks

4 What are spring and Autumn migrations?

5 Write briefly on Chilka Lake bird sanctuary

6 Properties of a social group

7. Advantages of living in a social group

8 How different casts are formed in bees?

9 What type of groups rhesus make?

10 what do you understand by proximate and ultimate interpretations?

Section -C (Long Answer Type)

1 Draw section of human brain ,label it, and write functions of major parts.

2 Write a note on limbic and reticular systems

3 How many types of biological clocks are found? Where is it located?

4 Write a note on bird migration and navigation.

5 Describe social organisation in langurs.

6 Describe social grouping in honey bees.

7 Explain Reproductive success ,Darwinian fitness, Individual fitness, Kin selection, Group selection

8 Using appropriate examples explain altruism and cooperation in animals

Answer Key of Section-A

1 Paul D MacLean

2 Mesencephalon

3 Infrastructure of speech

4 Thalamus

5 cerebellum

6 limbic system

7 True

8 True

9 Matutinal

10 false

11 Chronobiology.

12 True

13 True

14 False

15 Migratory restlessness

16 Longitudinal migration

17 True

18 False

19 One male-many female/harem groups

20 false

21 glands on abdominal segments 4-7

22 Sociobiology

23 True

24 True

25 Fitness

Unit - 10

Social Organizational Orientation and Communication

Structure of the unit

1.2 FEEDING STRATEGIES

Animals feed by tearing, ripping, biting,nibbling, grazing, browsing, sucking, engulfing, chewing, entangling and filtering.

There are however following major types of feeders in animal kingdom

1. Heterotrophs
    1. Non selective feeders – Grazers
        1. Grazing rumination strategy
        2. Other strategy
    2. Selective feeders - Browsers
        1. Cutting and chewing strategy
        2. Strategy of arboreal browsers
        3. Strategy of aquatic browsers
        4. Bark, root, bulb, eating strategy
        5. Strategy for sucking plant juices
        6. Flower, Pollen, fruit and seed eating strategy
        7. Mining and burrowing strategy
        8. Deposit and suspension feeding strategy
        9. Filter feeding strategy

3. Predatory strategy
    1. Strategy to eat sedentary prey
    2. Strategy to catch moving prey
    3. Strategy to use sonar
    4. Strategy of cooperative hunting
4. Parasites
5. Saprotrophs
6. Miscellaneous
    1. Commensalism
    2. Symbiosis
    3. Courtship feeding
    4. Parental feeding
    5. Food sharing
    6. Brood parasites

A full understanding of animal species is acquired only after years of extensive studies in their natural environments. Each species is faced with unique problems depending on the type of environment in which it lives, whether it is in snow, desert or jungle, whether it is a toad, a tiger or termite. The species have evolved their own strategies – (a strategy is a plan or method to achieve something over a period of long time) e.g. feeding, sexual, aggressive and parental which enables them to survive in their respective environments. A successful individual not only survives but also reproduces to pass its genes to the next generation. However, only those individuals who are best adapted to their environment survive, and they transmit their genes to their offspring, a phenomenon called 'survival of the fittest'. All organisms require an energy source and nutrients for growth, maintenance, activity, reproduction and survival. Feeding provides energy for all this. Animals have evolved different methods or strategies to procure food from their respective environments. Feeding Strategy deals with variations shown by different species in the style of feeding mechanisms. All animals may it be amoeba, anemone, ascaris, leech, prawn, mosquito, unio, starfish, toad, salamander, petromyzone, shark, snake, vulture and human need food and have the ability to process it according to their requirement. Feeding is simply the means of acquiring the materials for building, developing and maintaining the animal’s body and gonads to carry on the next generation.

There is a vast variety of food from decomposing organic matter, roots, stem, leaves, flowers, fruits, resin and nuts; animal prey is varied from tiny planktons, krill/ shrimp, smaller fish for larger fish in the ocean to small vertebrates to deer/antelopes on the land. The behaviour of a nectar-feeding hummingbird probing a flower with its bill contrasts markedly with the swift, sudden dive of a hungry eagle. A lion's fearless meat eating, an antelope or a caterpillar's noisy crunching of a leaf. There is a great variety in parasitic mode of life and food. The range of food and feeding methods is very wide and depends on where does the animal lives, what is its energy requirement and what can it eat? In sea and **fresh water algae and weeds** are the predominant **green plants** available to fish, turtle and other smaller creatures**.** In turn the smaller animals are available to larger water animals. On **land**, plants are represented by **many taxonomic groups** and take a variety of forms - **algae, mosses, ferns, grasses, succulent herbs, and trees**. The scope for plant feeding is greater on land. Predators operate differently in water and on land, and their spatial relationships to their food are not the same; put in its simplest terms, an **aquatic predator** chases its prey in a **three-dimensional** arena, whereas on land the chase is usually on the ground. The range of organisms and their feeding activities is so great that generalization is impossible: they feed by **tearing, ripping, biting**, **nibbling, grazing, browsing, sucking, engulfing, chewing, entangling and filtering**. Excretion of undigested food is an integral part of food and feeding. Fungi and some internal parasites feed entirely by absorption and make use of everything that they ingest, but the food of most animals include indigestible components that must be excreted. The indigestible component may be small or large; in blood-sucking flies and nectar-feeding insects it is negligible compared with the volume of plant fiber that passes almost unchanged through an elephant's gut. Owls and other birds of prey regurgitate pellets composed of fragments of fur, bones and hard insect exoskeletons that they cannot digest.

Green plants utilize solar energy and manufacture organic substances from inorganic compounds; all other organisms ultimately depend upon them for food. A big tree is the starting point of food chains along which the energy flows, for example one such food chain could be : **Banyan tree** ---→▶ moth/butterfly/insects/ caterpillar--▶- lizards--▶- small birds –--▶ snake and hawk . A relatively small part of the Banyan tree is consumed while it is alive; the bulk is used as food , after it dies giving rise to a second food chain starting with decomposer –▶ larvae/insects/earthworms/molluscs –▶ bigger insects/ molluscs---▶ frogs/lizards/ small birds---▶ snakes--▶-larger birds-carnivores. Most land plants are only partially consumed while alive. Woody supporting tissues that form the bulk of vegetation become available as food after death of the tree. On land , therefore, primary **decomposers** are more important than primary **consumers.**

Most animal species do not fit neatly into one **trophic level**. For instance, **nectar-feeding wasps** also feed on insects to their larvae as they require high concentrations of protein for growth ; female **mosquitoes** require a **blood** meal before egg lying, although males feed only on **nectar**. Seasonal availability affects diet; **red foxes** are predominantly predators of small mammals but eat insects and fruit in summer and autumn, and the **black faced dioch** a pest of seed crops eats **termites** and other **arthropods** during the rainy season. Many animals are opportunist and feed on whatever is available. Like-**man and pig** they are **omnivorous** eating almost everything. The diet of many species includes both plants and animals . **Rabbits** though predominantly **vegetarian** eats **snails** when they encounter them in the grass, the slug a common garden pest readily eats grass ,moss , worms and small insects . Many **butterflies** eat **faeces** as readily as **nectar** and **fruit juices**. **Blue tits** and other birds have learned to open **milk bottles** and eat the cream.

There are following major types of feeders in animal kingdom

1. **Heterotrophs** (feeding on live plants or animals)

   A. Non selective feeders : grazes

      (i) Grazing rumination strategy

      (ii) Other strategies

   B. Selective feeders : browsers

      (i) Cutting and chewing strategy

      (ii) Strategy of arboreal browsers

      (iii) Strategy of aquatic browsers

      (iv) Bark, root, bulb eating strategy

      (v) Strategy for sucking plant juices

      (vi) Flower , pollen, fruit and seed eating strategy

(vii) Mining and burrowing strategy

(viii) Deposit and suspension feeding strategy

(ix) Filter feeding strategy

C. Predatory strategy

(i) Strategy to eat sedentary prey

(ii) Strategy to catch moving prey

(iii) Strategy to use sonar

(iv) Strategy of cooperative hunting

2. **Parasites** (deriving nourishment from plants or animals by harming them)

3. **Saprotrophs** (feeding on dead decaying organic matter and cleaning the environment)

4. **Miscellaneous**

A. Commensalism

B. Symbiosis

C. Courtship feeding

D. Parental feeding

E. Food sharing

F. Brood parasites

1. Heterotrophs

Heterotrophs derive food from other organisms adopting many strategies. **Heterotrophic** organisms are consequently diverse in form and function and include all animals from the great **whales** to microscopic **protozoans** . All depend on **green plants.** Heterotrophs can exploit various parts of a plant, flowers, leaves, stems or roots. Some **termites** are able to feed on dry, dead wood because they **harbour** flagellate **protozoans** that digest cellulose. Many carnivorous mammals supplement their diet with plant material e.g. **African serval cats** also eat vegetables.

Animals feed to gain energy and all food-gathering activities require energy; so if the animal has to grow and reproduce then the calorific content of its food must be high enough to provide a net gain . To some extent this determines what a predator likes as prey and explains feeding preferences; the greater the yield of a single feed, more will be the gain in energy and nutrients. A **fox** that catches a **rabbit** is better, because it feeds more efficiently, than one that spends all day digging up **beetle grubs**, even though the total nutrient and energy content may be the same. The energy costs of finding beetles are much higher and the net gain .The volume of food that has to be ingested to acquire sufficient energy and nutrients profoundly affects the internal anatomy, the shape and the feeding behaviour of animals. **Herbivores** spend much of their time feeding; they **process large amounts** of relatively indigestible food often of **low protein content**, need to retain it for a long time, and have longer and more **spacious guts** than carnivores, predators not only have to eat less but have shorter guts and are leaner in build. A newly hatched tadpole feeds on plants and has a long coiled gut, which gives it a bulbous shape; later it becomes carnivorous, the gut shortens and the shape becomes more streamlined. Not only is animal food different in quality from plant food, it is more patchily distributed, less readily available, less accessible, less predictable and may actually run away just when a meal seems within reach. Predators therefore, need to derive as much food as possible from a capture. A wild cat may eat equal to one third of its body weight at once, but it digests the meal and assimilates the nutrients efficiently in comparison with a herbivore. Differences in the quality and availability of their food have led to the evolution of differences between **animal- and plant-feeders** in anatomy, digestive chemistry, feeding behaviour and offensive and defensive strategies.

The feeding strategy of **carnivores** e.g. **centipede or a shark** is based on a **search and strike strategy** , **mantis** lie in wait for their insect prey, but once it is within reach, they grab with speed and precision, **lions** stalk antelope, concealing their approach by crouching low amongst vegetation, but once within range they pounce dramatically unleashing their strength and power. In contrast, the feeding strategy of **herbivores** is by **camouflage and deception strategy-** to minimize the risk of falling prey to a predator .

Plant food is plentiful therefore, it seems that herbivores have no shortage of food ; but even plants are adapted in many ways to minimize loss of their **photosynthetic** and support structure to herbivores. **Thorns, hairs, poisons and hard tissues** make leaves and stems unpalatable; thus, despite apparent abundance, the availability of plants as food is limited. The massive trunk of an oak tree can be regarded as support for the leaves where photosynthesis occurs, and the spreading branches as the means for holding them in the light whereas, the **tannins** and **waxy cuticle** developed by oak leaves are adaptations to **minimize defoliation** by caterpillars. The caterpillars of **monarch butterflies** feed on **milkweed plants** containing highly **toxic cardenolides**. They store the poisons without harm and themselves become unpalatable to predators both as larvae and adults.

The herbivores use different methods (strategies) to eat food depending on their body size, group structure, habitat, food availability and food dispersal.

A. Non- selective feeders : Grazing

The **Grazers** eat indiscriminately ,generally on grass .Grass makes a good grazing food. It is **palatable, widespread, and** abundant and, since grass mostly does not grow more than a meter in height, it is **accessible**. The predominant grazers are mammals: **rabbits and hares; rodents; kangaroos; and above all, the large hoofed mammals (ungulates) which include horses, cattle, antelope, sheep, llamas and hippopotamuses.** These, together with **grasshoppers** and various sorts of **termites**, are characteristic grassland animals, but grass is also eaten by **snails, slugs, butterfly and moth larvae, tortoises, geese and even grass carp**, which graze on submerged vegetation.

In grazing mammals the teeth have been modified as tools for cropping fibrous grass and grinding it to release the cell contents and fragment cellulose, the incisors cut, the cheek teeth chew and a toothless gap between them, the **dias-tema ,** provides space for movement of food by the tongue. **Horses** bite with their self-sharpening incisors and can cut through tough fibrous stems. **Cow, sheep** and most other **even-toed ungulates** have no upper incisors, only a **horny pad** that acts as a sort of cutting board for the lower teeth. **They** are adapted for eating lush grass that they twist around their **mobile tongues**, hold against the incisors and pull free. **Sheep's split upper lip** means that it can nibble at short grass. The adaptations of ungulates for cutting and eating grass are concentrated in the head - even the tongue is used for grasping and holding - and the limbs remain free for rapid sustained movement, but many rodents use the forelimbs when feeding e.g. **squirrel** ,**cane rat**, a large rodent common in Africa. The action of the teeth and jaws of grazing mammals ensures that finely shredded grass enters the digestive tract. **Digestive enzymes** break down all the soluble nutrients but there is still the problem of dealing with cellulose and, here too, grazing ungulates, rodents, rabbits and marsupials have independently evolved the same solution. They employ **cellulose-splitting microorganisms**, either bacteria or, in the case of *Hippopotamus*, cattle and their relatives, a complex flora and fauna of bacteria and **ciliated protozoans**. All have an enlarged section of the digestive tract, which houses the microorganisms. Rodents and rabbits become inoculated with the appropriate bacteria by eating maternal faeces; young ungulates commonly eat earth at the stage when they are starting on solid food and probably acquire their microorganisms in this way.

Geese use the **lamellate edges** of their **flattened bills** to crop grass, **tortoises** use the **sharp edges** of their **horny beaks, Birds** have a highly **muscular stomach** region, the **gizzard**. The cutting and **chewing mechanism** of **grasshoppers** and **termites** is quite different from that of grazing mammals. Paired mouth appendages move the food between pair of **mandibles** with tough, toothed edges and grinding surfaces. **Snails** and **slugs** have jaws and a **radula** to tear off particles , which become entangled in mucus and move back into the oesophagus.

(i) Grazing- rumination strategy:

Large grazing mammals spend much time feeding to acquire sufficient nutrients and energy from a relatively indigestible food source. Consequently they must spend long periods away from cover in exposed situations. The **ultimate adaptation for grazing is rumination,** which involves quickly eating large quantities of grass, then move to a safe place-regurgitate food, chew and digest (rumination) at leisure and in safety. In this process the freshly cropped food is swallowed without chewing and passes to the **rumen**, the **first and largest of four stomach** chambers where cellulose is digested by **bacteria and ciliates**. When a cow drinks water, a groove running from the oesophagus closes off to bypass the first two stomach chambers, and in a calf before weaning, the first three chambers are small and milk passes straight through them. The ruminant system with its flora and fauna of microorganisms is adapted for the intake of large amounts of relatively indigestible food of low nutritional value and for reduction in the time spent actually feeding and exposed to predators. **Rumination** is fully developed in the **cattle** family, in **deer** and in **giraffes**, they have four chambered stomachs and are sometimes collectively called ruminants.

(ii)Other strategies:

Mammals have evolved different for using the products of bacterial digestion and for reducing feeding time. **Cellulose digestion in rodents, rabbits and**

hares occurs in the **caecum / appendix**, then the food passes through the small intestine, but the lining of the lower intestine, has only limited power of absorption, so at night, **rabbits excrete** moist, **mucus-coated faecal pellets** which they **promptly eat (coprophagy)**. The complete cellulose digestion and absorption takes place during the second journey through the small intestine. By day, dry faecal pellets are excreted and discarded.

B. Selective feeding : Browsing

(i) Cutting and chewing strategy :

Browsers feed very selectively on leaves, fruits, seeds, and soft stems and on insects. Plants grow in a variety of forms sizes and shapes from **seaweeds to cactuses and grasses to forest trees.** Some animals chew plant tissues and others suck plant juices. **Giraffes** browse on shrubs and trees, especially acacia leaves, **pruning** them delicately after removing the thorns. Their incisors are **spatulated** enabling them to pick leaves from the trees. Their upper lip is **prehensile** and the **lips are covered with pointed papillae**. The **tongue is long ,muscular** rough and with small fleshy spines. The roughness of lips and tongue removes thorns , which come with acacia leaves . Their thick viscous saliva provides further protection against thorny food. In Venezuela, caterpillars of the ithomiid butterfly, *Mechanitis isthmia*, feed on a horny species of Solanum. They spin a silken web on the horns over which they crawl to feed safely on the unprotected leaf edge.

Royal antelope of Africa is a selective leaf eater(folivorous), browsing on **Acanthaceae fallen leaves** , they have elongated, **prehensile snouts** to pluck vegetation. The **giant panda of China** is not a generalist but highly selective and feeds only on **bamboo shoots.** Surprisingly **African elephants, which seem to be eating anything green** are predominantly **browsers** . The sensitive and mobile trunk is used to pluck vegetation and convey it to the mouth and is also used for drinking, sucking up 4 liters at a time and squirting it into the mouth. The **trunk** is actually enormously elongated **nose**, the tip of the trunk is **upper lip**, with the nostrils opening at its tip. Tiny objects can be picked up using the upper lip .The **tusks** are an enlarged pair of upper incisors used for **scraping bark** from trees and in defense, and perhaps form a protective guard around the vital trunk when pushing through dense vegetation. Four massive **chewing teeth** with transversely- ridged grinding surfaces are present in the mouth . An average **adult weighs 3500 kilograms**, an old **bull over 6000 kilo-grams**. They feed for up to 24 hours a day and daily food intake is four per cent of live weight for most size and age classes, but more for lactating females. Elephants do not ruminate although bacterial fermentation of cellulose takes place in the enlarged caecum and colon. Food passes through the gut in **12 hours** whereas it takes **24 hours in a horse** and **72 hours in a cow,** and, since elephants' food contains a high proportion of cellulose and fiber, nearly half the' intake is defaecated. Elephants also eat bark and roots when their diet is deficient in fiber, their calcium needs are enormous for a massive skeleton and especially for the tusks.

(ii) Strategy of arboreal browsers

Since most of the leaves in a forest are up in the canopy, there is a selective advantage for forest browsers in **climbing or flying**. The **Flying squirrel of Sita mata Reserve near Chittor, Rajasthan** climbs the tree, it has a furry membrane between fore and hind limbs with which it can **glide** from tree to tree. It eats mainly fruits that it plucks from twigs with its long **incisors**. The **sloths** of South America are fully **arboreal leaf-eaters** and their **skeletons and muscles are adapted for hanging from branches** by the massively **clawed, hook-like hands and feet**. Agile **monkeys and lemurs** eat a varied diet(folivorous- leaf ; frugivorous-fruits), but some, including the **indris of Madagascar**, the **howlers of South America**, and the **colobus monkeys of Africa** and **hanuman langurs of Asia**, are predominantly **leaf-eaters, but in cities and temples they are seen eating provisioned food such as bananas and chanas, but they are predominantly folivorous and hence are browsers**. The cheek teeth of these different gliding or climbing leaf-eaters are modified in various ways for **shredding and grinding** their food and all have enlarged gut sections - stomach compartments, large intestine or caecum - where bacteria digest cellulose. The **koala**, an Australian marsupial, feeds exclusively on aromatic *Eucalyptus* **leaves**. For about a month before the young begins to feed on leaves, the mother produces special, half-digested faeces that the youngster licks directly from her anus. Apart from contributing to the infant's nutrition this **inoculates** it with the gut flora necessary for digestion of Eucalyptus leaves.

(iii) Strategy of aquatic browsers

The producers of the open sea are microscopic **phytoplanktons**. **Protozoans, Sponges, Coelenterates**, **Crustaceans,** and the **larvae** of many marine animal feed on planktons like predators rather than browsers. At the coasts are found **seaweeds** on which larger animals browse like their terrestrial counter parts.

Largest of the browsers are-.**sea cows - the manatees(aquatic mammal)** of Atlantic coasts and the **dugong** of the Pacific and Indian Oceans. Vegetation is plucked will the **mobile, fleshy lips** and cropped by horny pads. But it is **molluscs** that are the predominant coastal browsers and these include **chitons, limpets, top-shells, and sea-hares.** Various tropical freshwater **fish** exploit planktonic plant life, and others browse vegetation. **Cichlids** , **Carps,** and many other fish of several genera browse on aquatic plants.

(iv) Bark, root and bulb eating strategy:

Elephants use their tusks to **strip bark**, **rabbits and rodents gnaw** at it and **deer rasp** it with their lower incisors. The phloem (food-transporting tissue) lies just below the bark of a tree, is highly nutritious, and in some instances provides essential minerals otherwise deficient in the diet. All these animals also ingest quantities of wood and fiber and depend on their dental and digestive apparatus to deal with it. In South America, **white-eared marmosets** scrape the bark of **gum trees** with their teeth and lick the oozing sap. In some areas this is an important component of their diet and marmosets defend their private gum trees against intruders.

Many **root-feeders** burrow into roots destroying them in situ but a variety of animals actively dig for roots, **tubers** and other underground plant structures. **Roots, tubers, corns and bulbs** represent a **plant's store of food** for survival through an adverse season and often provide resources for the growth and development of flowers at a season when photosynthesis is minimal. Consequently they are a valuable source of concentrated, highly nutritious food for animals. But they are below ground and therefore protected. Only **animals with tusks, hands or some other digging** facility can reach underground storage structures . **Pigs** locate them by smell and use their muscular, elongated snouts, **baboons** use their **hands** to excavate food , and the ducks are adapted at loosening the roots of aquatic plants with their bill.

(v) Strategy for sucking plant juices:

Spittlebugs and cicadas suck sap from **xylem**, the tissue that transports water from the roots of plants up to the leaves. It is an unlikely food source as the sap consists largely of water. Amino acids form 98 per cent of the dissolved organic matter and it is these that spittlebugs and cicadas use as food . This entails taking in large quantities of water and excreting most of it. Dilution of the body fluids is avoided because their gut is looped and water is shunted rapidly across the gut walls directly into the hindgut leaving an increased concentration of amino acids in the mid gut .

Aphids suck sap from phloem, the food -transporting tissue of plants. In contrast to xylem, phloem sap is **rich in sugars** but like xylem contains only low concentrations of amino acids. Aphids have tackled the problem of acquiring sufficient nitrogen in several ways. **One simple strategy**, common to all, is to ingest lots of sugary fluid so that sufficient amino acids are absorbed and continuous excretion of excess sugar as **honeydew.** A **second strategy** common in temperate regions is to alternate between two food-plants. In Northern Europe, **cherry-oat aphid** feeds on **leaves in spring** when amino acid concentrations is high in leaves. As leaves mature, soluble nitrogen content falls and aphids leave cherry to spend summer on grasses , which by this time are growing rapidly and hence contain high levels of amino acids.

Whitefly, and **spider mites** pierce single plant cells with the mouthparts and suck out the cell sap that contains a wide range of nutrients. Despite their totally different structure, several species of **sea slug** feed on the cell sap too.

(vi) Flower, pollen , fruit and seed eating strategy

The reproductive organs of plants , their fruits and the seeds have a high nutrient and energy content that different animals exploit as food. since flowering plants cannot move from one place to another; they are dependent on external agents to **transfer sex cells** from one individual to another and also for dispersal of the seeds that constitute the next generation. **Wind and water** transport pollen and disperse seeds, animals also do this job. By providing, attractive food such as nectar and fruits, plants ensure that flowers are visited, and that seeds are ingested, and later excreted intact. **Flower-visitors(e.g. bullfinches, house sparrows, earwigs and click beetles , fly larvae and caterpillars of many** species develop in flower buds) that effect **pollination** and **fruit-eaters** that **disperse seeds** further the evolutionary aims of the plant. Petals form the most conspicuous part of a flower they attract insects and other animals that effect pollination. Provision of nectar is an evolutionary strategy of plants to ensure visits by pollinators, but nectar is produced at some cost to the plant. It is a concentrated sugar solution containing glucose, fructose and sucrose and hence is a rich and easily assimilated source of energy, which serves as ready fuel and a reward for flower-visitors. It also contains a range of amino acids and consequently satisfies protein needs as well. **Grasses and other wind - pollinated flowers** have neither showy petals nor nectar and are rarely scented, they do not need to expend energy on such things.

Beetles are equipped with **biting, chewing mouthparts**. The habit of visiting flowers to eat pollen has arisen in many families and some flowers are mainly pollinated by beetles. Other insects are specially modified for eating pollen, a feathery little moth, **Micropterix calthella**, has biting, chewing mouthparts with which it eats **buttercup pollen**; and both sexes of **hoverflies** eat pollen as well as nectar. The **drone fly- Eristalis tenax** seizes a quantity of pollen between the fleshy lobes at the end of the proboscis, moistens it with saliva and sucks pollen grains suspended in saliva into the mouth.

Different species of **Bees** , solitary and social collect pollen to carry back to the nest as food for the larvae, often mixing it with regurgitated honey (processed nectar) to make it easier to transport. Most of the body hairs of bees are branched and feathery so flower visitors become dusted with pollen. Tropical American **butterfly Heliconius** extracts nutrients from pollen in an unusual manner. The proboscis bears tiny processes at the tip that are used to collect a dry mass of pollen on its ventral side near the head. This is moistened with regurgitated nectar and are **crushed** for several hours by **coiling and uncoiling the proboscis**. This actively releases proteins and amino acids when treated in this way and the butterfly sucks up a solution of pre-digested nitrogen compounds. Largely as a consequence of this unique adaptation for acquiring protein, Heliconius live far longer than most other butterflies and the reproductive life of females continues for six months.

The grains of pollen of a plant must be transferred from the stamen of one flower to the pistil of another flower of the same species. Only then can the fruit, and the seeds within it, develop. What strategies stationary plants, rooted in one place, use to transfer grains of pollen from flower to flower? Many animals serve as pollinators for plants. How do they do this? Plants use the communication channels of animals to transmit messages to them. They use color and smell to attract the animal. If the animal responds to the message and visits the flower, sweet nectar and tasty pollen are its nutritious reward. Many flowers have special "signs" that point to the location of the nectar. These "nectar trails" are marked on the flower by a different colour. The pollinator follows the trail of colour to the place where the nectar is hidden. Thus, the flowers transmit a message to the pollinators: "Help yourselves, and help me, too" The **birth wort plant**, has a deep cup like flower which is pollinated by flies. The plant uses the aroma of its flowers to attract insects. Most plants are pollinated by insects, but there are some that are pollinated by birds, and even by mammals. The method that each plant uses to attract the pollinator depends on the messages that the pollinator can receive. Birds, such as the hummingbird, see red and orange clearly. Therefore, most of the flowers pollinated by the hummingbird are either red or orange. Some species of bats pollinate plants. Since **bats** are active at night, those flowers that are pollinated by bats are very large and usually have a light color that stands out in the dark. Moreover, the flowers have a heavy aroma that attracts the bats.

Deceiving Pollinators: Most orchids don't offer pollinators any payment for their services. The orchid has no nectar and the pollen is not edible. So how do orchids attract pollinators? They do so by deception and trickery! The strategy used by **ophrys flower** is that the scent of this flower is like the sex pheromone of a female bee therefore, it attracts male bees from far away. The flower has the same shape and colouring as the female bee. It also has the same velvety texture. So, when the male lands on the flower, he even tries to mate with it. The pollens of the ophrys stick to the male bee's body. If the bee repeats this mistake with another ophrys and tries to mate with it - he will pollinates the other flower. The **Arum lily** uses another strategy to attract and trap pollinators in its jug-shaped inflorescence . The arum lily smells like a decaying carcass, excrement or sweat. The odour attracts flies looking for food and a place to lay their eggs. The flies enter the inflorescence of the Arum lily. They can't get out because special hairs block their exit. After a day or two, the arum lily flowers release fresh pollen, which covers the flies. Then the hairs that blocked the exit wither. The flies escape and go off to pollinate their next arum lily. They pollinate each arum lily with the pollen that they picked up from the last arum lily that they visited.

Insects are not the only flower-visitors. **Field mice** in South Africa and **small marsupials** in Australia , **bats** eat both nectar and pollen from a variety of different types of flower and are important pollinators . Among birds, the **hummingbirds** of the Americas are the best-known flower-visitors, but there are others too, including **Hawaiian honeycreepers**, **sunbirds** and **brush-tongued parakeets.** Hummingbirds feed while hovering in front of a flower and can protrude the tongue, which is supported by bony rods encircling the skull, far beyond the end of the beak. The grooved tongue has brush borders at the tip that soak up nectar by capillary action and, when the tongue is retracted into the beak, the nectar is sucked back and swallowed. Other nectar-feeders have similar tongues.

The flower withers and the petals drop. But within the ovaries a further burst of growth and metabolic activity produces seeds and the plant is again a focus of feeding activity. This is partly because seeds are nutritious but also because of the ingenious adaptations of plants to ensure seed dispersal. There are disadvantages in seeds germinating beneath the parent plant where they would compete with it for light, space, water and nutrients, and plants have evolved a variety of devices and structures for dispersal. One such **evolutionary strategy** is the development of palatable tissues around seeds to form a fruit.

The flesh of most fruits is sweet and juicy; it has food value largely as a source of carbohydrate, vitamin C and water. The skin is usually brightly coloured so that fruit is conspicuous and attractive. All sorts of animals eat fruits. In season **monkeys, apes, man, marsupials such as phalangers and cuscuses, bears, racoons, civets and many birds including tanagers, toucans, barbets, turacos and thrushes are frugivorous**. They digest the flesh and either regurgitate or excrete the seeds some distance from the parent plant. These are legitimate fruit eaters, the plants provide them fruits in exchange for dispersal of their seeds. Most casual fruit-eaters are vegetarians or omnivores and require no special adaptations for dealing with this food. **Palm nut vulture** eats the **vitamin-rich fruits of the oil palm** .The larger **fruit bats**, some of which have wingspans approaching 150 centimeters, are nocturnal fruit-eaters, crushing pulp from soft fruits like banana with their broad, flattened molars. Often they extract only the juice and reject the pulp together with the seeds; or they swallow pulp and seeds, digest the pulp rapidly and excrete intact seeds , that germinates. Many **parrots** and **pigeons** take fruit in order to eat the seeds. Other fruit feeders eat only the nutrients surrounding the seeds**,** **plant bugs**, **mealy bugs** and **scale insects** suck juices from fruit .Several **moths** have tough, barbed tongues with which they pierce and penetrate fruits to suck the juice; a small **sting less bee**, **Trigona trinidadensis***,* feeds on citrus fruits; and tropical American **orioles** feed on large fruits by stabbing the skin, then forcibly opening the beak within the fruit and eating the juice and pulp which flows between the mandibles. Insects that feed internally in fruits, such as the **larvae of moths, weevils and fruit flies**, contribute nothing to dispersal .

A hard covering may not be adequate protection for a seed. **Rodents** are able to sit up and use the forelimbs to hold food and can then open nuts by using the incisors in a number of different ways. **Finches** have horny mounds and ridges inside the mouth against which they hold nuts or seeds while rotating them against the sharp edge of the lower mandible thus cracking and cutting off the shell. The massive beaks of **hawfinches** generate a force of 40 kilograms to crack cherry stones; the jaw muscles are exceptionally large and are wrapped round the skull. In **parrots**, both upper and lower mandibles are hinged on the skull so that seeds can be opened .Many birds which swallow seeds whole have horny ridges in the lining of the **muscular gizzard** and also swallow small stones. **Hickory nuts** disintegrate in a **turkey's gizzard**. **Quelea quelea** maximizes exploitation of grass seeds in the African savanna by **communal feeding** . When a flock settles and feeds for any length of time, it is gradually joined by other flocks flying from all directions until many thousands are together. This method of feeding increases the chances of an individual finding a good feeding site. Late in the dry season, when grass seeds are hard to find, the **flocks feed in a characteristic way**, all aligned and moving in one direction. Those at the rear are covering ground already picked clean, and they continually fly to the front of the flock, only to be overtaken by others in their turn. The effect is of a gigantic roller movement across the grassland, accompanied by continuous chirping, which orients the outliers. **Squirrels and weevils** often account for 90 per cent of acorn crops in temperate forests, and in some years, **kangaroo rats** consume 95 per cent of the seeds of their preferred food-plant .

(vii) Mining and burrowing strategy

Food supply and protection from predators are combined in those animals that **burrow into their food**. Many animals burrow into soil, mud or sand for protection, and a few of these species eat the material they excavate, but since only a small proportion of their surroundings is edible, such animals ingest a high proportion of inorganic material. On the other hand, for miners and tunnellers in living plants or wood, feeding and excavating are the same exercise. **Woodborers** are the champion tunnellers , **blowfly maggots** and other scavengers burrow deep in their food; and many internal parasites move hungrily through the tissues of their hosts. **Leaf- and stem-miners-** leaf miners are protected from physical damage and climatic extremes. Each has abundant food. It seems an ideal life style but they are not especially protected because predators and parasites have evolved skills in locating and reaching them, and mined leaves may be shed prematurely. The green gloss of many holly leaves is disfigured by a yellow or brownish blotch that indicates the presence of a leaf miner e.g. *Phytomyza ilicis.* The insects that make leaf-mines all belong to groups with a true larval phase, and it is the larvae that mine leaves. The majority are **moth caterpillars or fly larvae** but a few **sawflies and beetles** feed and develop in this way. There is little space between the upper and lower surfaces of a leaf, therefore, leaf miners are all small. They tend to be rather flattened in shape. As they chew their way through the nutritious photosynthetic tissue of the leaf blade, they encounter little that is indigestible other than cell walls. They defaecate within their mines, and lead a completely self-contained existence.

Wood-boring insects - species of **goat moths** tunnel into the solid wood of a variety of living trees in different parts of the world and all cause considerable damage. **Caterpillars** have no means of digesting cellulose and so have to consume vast quantities of wood in order to acquire sufficient nutrients for growth and development, it explain why some goat moths remain as caterpillars for three or four years. Their tunnels are large and extensive, and **goat moth** damaged trees characteristically exude copious sap on which other insects, including **hoverflies and wasps**, feed. **Bark beetles** are notorious because those that tunnel in **elms** spread the fungus that causes a disease. They are unusual amongst wood-boring insects in that adults as well as larvae make tunnels. Other beetle larvae bore deep into the wood of trees, among them the **longhorn beetles**. Most longhorns, like other woodborers tend to attack unhealthy or dead plants, and only a few species are found in vigorously growing trees. More insects are able to gain access to wood when it is dead than when it is alive. The most successful invaders of dead wood are undoubtedly certain **termites that harbour large flagellate protozoans**, which ingest wood particles and digest cellulose. Without these **symbiotic flagellates** these termites slowly starve. Some may have **bacteria** capable of digesting cellulose.

The marine woodborer, the **shipworm,** is a bivalve **mollusc** . They settle on wood, attach themselves by a **sticky thread**, change the form of shell and foot, and start **burrowing.** The paired shell valves lose their firm attachment to each other and become the cutting tool, the **sucker-like foot** protruding between the valves, rotates them through 180 degrees first one way and then the other so that a circular tunnel is formed into the wood. It gets longer and more worm-like as the tunnel extends. Because of their efficiency at consuming and digesting cellulose, **shipworms are very destructive borers**.

Soil-eating strategy - Many burrowers eat indiscriminately as they tunnel, excreting soil or sand particles cleaned of everything organic and nutritious. But soil, sand or mud, however rich in **humus or organic deposits** are largely non-nutritious. The most familiar of the eating excavators are **earthworms**. They can push through loose soil by alternate contraction and expansion of circular and longitudinal muscles in the body wall, anchoring themselves by bristle-like setae, but also burrow by eating. In temperate regions, there may be as many as **five million worms per hectare** below old grasslands and orchards where the soil is undisturbed and there is plenty of food in the form of decomposing vegetation. Termites species eat soil and digest its organic component. But their activities are centered in their nests and they use their **copious excreta** of fine clay to construct complicated nesting mounds. The feeding and burrowing activities of **termites, earthworms and insects** are relatively well known, because they are accessible. We can observe, investigate, measure and experiment on terrestrial animals with comparative ease. It is far difficult to see or even visualize exactly what aquatic invertebrates are doing e.g. **Lugworm** *Arenicola* burrow about 20 to 30 centimeters vertically into muddy sand by a combination of **eversion of the pharynx** and mucus secretion, and then turn horizontally, so that they come to lie in L-shaped galleries. When *Arenicola* feeds, it engulfs sand by repeated eversion and retraction of the pharynx. Like all sand-eaters, Arenicola has a long, thin and distensible gut allowing accommodation of bulky material . Just as earthworms are more abundant in humus-rich soils, there is a good correlation between the total number and size of lugworms and the percentage of organic nitrogen mixed with sand. Engulfing the substrate is a simple way of combining feeding and burrowing, and representatives of several other marine groups have adopted this strategy, *Chaetoderma* is a mollusc without a shell, which burrows through deep-sea bottom oozes; *Leptosynapta* **(echinoderm)** is a burrowing **sea-cucumber**, related to starfish and sea-urchins but looking more like a polythene tube full of sand. **Acorn worms** feed as indiscriminately as Arenicola but in an entirely different way. They live **in mucus-lined burrows** but feed in temporary shafts leading off the main one. As the proboscis is moved about in the sand, particles adhere to its mucous coating, and the beating of tracts of cilia **concentrate the mucous sheath** into a ring at its base. The front end of the digestive tract is also lined with cilia and their action draws into the mouth a continuous string of mucus laden with sand grains and food. Finally, the **heart urchin or sea-potato**, is far from worm-like, although modified for burrowing. They live between 15 and 20 centimeters below the sand surface with which contact is kept by a respiratory tube built and maintained by special, long, **hydraulically operated** tube feet. Mucus covered **tube feet collect sand particles** and scrape them off against a **grill of spines** that arch over the mouth. Cilia then move the particles into the digestive tract, food is digested away, and cleaned particles are excreted into a blind-ending sanitation tunnel.

(viii) Deposit and suspension feeding strategy

The fine drops of organic material that drips down can either be captured while in **suspension** or can be scraped after it has **deposited** on the bottom. A number of species of marine gastropods such as **Turritella** and related **tower shells** found world wide, burrow just below the surface of muddy gravel, feeding on **suspended particles** brought into the mantle cavity by the inhalant respiratory current. Coarse particles are excluded from the inhalant opening by **feathery tentacles**, but finer particles are moved along ciliated feeding tracts on the mantle. Although they feed on particles suspended in the water, they inevitably stir up and then take in much deposited material including substrate particles. **Scrobicularia** is one of many **deposit - feeding** bivalves . A tiny crustacean, **0orophium volutator**, constructs V-shaped burrows into which it **scrapes surface sediments** with its **enormous antennae,** almost as long as its body. The respiratory current, created by the beating of abdominal appendages, draws the sediment through a filter of long, overlapping bristles on the second and third pairs of appendages. **Suspension feeders -** cockles **Cardium (Cerastoderma) and Owenia** are suspension feeders they use elaborate arrangements of ciliated surfaces waved through water to entrap food. **Owenia fusiformis** is a tube-dwelling **polychaete** bearing a crown of frilly lobes on its head. It can either bend over to sweep surface deposits with the crown or expand the water to trap suspended particles. All **starfish** bear cilia they trap micro-organisms and other organic particles that settle on them, they become entangled in mucus which is swept down between the arms and along grooves beneath the arms to the ventrally-placed central mouth. Some species of **brittle stars** move over the substrate picking up surface deposits in mucus-laden grooves beneath their arms.

Many shallow **sea shelter** a fragile, delicately coloured forest of coelenterates feeding by waving elaborately divided, mucus-coated tentacles in the water to entrap particles. The **plumose anemone**, Metridium, **sea-pens** and some **corals** feed in this way, and move food particles to the end of the tentacles by ciliary action, but, like all coelenterates, they have stinging cells to immobilize small animals and use the tentacles to put food into the mouth. Colonial **honeycomb worms** (family Sabellariidae), each inhabiting a tube constructed of sand grains, extend pink and brown tufts of mobile tentacles to entangle food particles and transport them to the mouth along well-defined ciliary tracts.

(ix) Filter-feeding strategy

Animals can also exploit rich food source by **straining organic particles (filter-feeding)** from water e.g. bivalves **Nucula** found in shallow waters, burrow with the probing, muscular foot, until they lie just below the surface of mud or sand. They then open the shell valves slightly and extend a pair of long palp processes that pick up fine particles. These are entangled in mucus and **carried by ciliary** action up **grooves on to the palps** between which lies the mouth. Fine particles enter the mouth, but coarser material is transported by cilia to the edge of the mantle lining the shell, and at intervals these **pseudo - faeces** are expelled by rapidly shutting the shell. Some food is also filtered from the respiratory current by the **leaf-like gills** and conveyed to the mouth by complicated tracts of cilia. Like many deposit-feeders they select by particle size rather than quality, but mucus mixed with food in the stomach, protects the delicate intestine from sharp mineral fragments.

Blue whales, the largest animals that have ever lived, are **filter feeders**, col-lecting vast masses of **shrimps.** They grow up to 30 meters in length and weigh150,000 kilograms , eat shrimps such as Euphausia superba only 7.5 centimeters long. The gulps are gigantic that after a meal a large whale's stomach may contain **10,000 kilograms** of food. Whales have sieve like structure called baleen in their mouth, which filters the food. They feed on planktonic animals that are tiny e.g. shrimp-like crustaceans, known as **krill** in **Antarctic** waters, and in the **Arctic** a more varied diet, including **crustaceans, cuttlefish and small fish.** Baleen whales are toothless, but filter plankton from the water through two dense rows of baleen or **whalebone plates** 250-400 in number , suspended from the sides of the upper jaw. When feeding, whales force water out through the baleen plates, and then gulp the trapped food .

Filter-feeding strategy in fish -The largest **sharks** are not ferocious man-eaters but leisurely **filter feeders**. The **basking shark**, which reaches 14 meters in length, swims slowly along with open mouth. As water flows into the pharynx and out over the gills, **plankton** is sifted from it by combs of long, slender gill-rays which fringe the inner openings of the large gill slits. The **whale shark**, which is even larger, swims with open jaws into shoals of **planktonic crustaceans, squid or small fish**. As it closes its mouth, forcing water through the gill slits, gill-rays retain food items. A slightly different system operates in the fantastic **manta ray** with a six-meter fin span it has curved lobes on the head that funnel small crustaceans and planktons towards the mouth and series of lamellated gill plates around the inner opening of each gill-slit filter small animals from the water.

Strategy to use beaks as strainers-Since **birds,** like whales, are air breathing, their filter-feeding systems show some similarities, and both have developed strainers on the sides of the mouth. In **filter-feeding birds**, the margins of the horny beak are lined with fine horny plates, or lamellae, which let through water but retain small organisms. **Shovelers** and other **ducks** feed by rapidly opening and closing their broad, flattened bills to strain muddy water and bottom deposits, and **whale birds**, a petrel, sieve plankton from Antarctic waters using the muscular tongue to force water between the parallel lamellae of the filter, much as a real whale does. But the most curious **filter-feeders** are **flamingoes** using their massive beaks .They eat small crustaceans, insect larvae and molluscs from bottom deposits, Flamingoes feed with a jigging(side to side or up and down) movement, sweeping their beaks through the water, while the pointed, spiny tongue rapidly pumps water in and out between the lamellae. Food is removed from the filter by the spines on the tongue as it retracts, and they can also eat mud by sucking it in with the bill closed and swallowing quickly before the tongue can expel it again.

Strategy to filter food using cilia -In contrast to whales, sharks and flamingoes, which move their filters through the water, most invertebrate filter-feeders are **stationary**, at least while feeding, and **move water through a fixed filter to extract food from** . It is no wonder that invertebrate filters are large and usually become the most conspicuous part of such animals. Ciliary mechanisms for food-filtering depend upon secretion of mucus to entangle and hold food particles; the beating of precisely arranged tracts of cilia sets up the feeding current, deflects food into food grooves and transports food laden strings of mucus to the mouth. A number of **invertebrate** groups have evolved **comb-like** arrays of ciliated tentacles called **lophophores** with which they collect food particles. Among these are **bryozoans**, **membranipora**, **and lampshells**. Many polychaetes are **filter feeders**, using filamentous tentacles surrounding the mouth. The **peacock worm Sabella pavonina** builds a tube of mud particles cemented together with mucus, when they feed, a delicate cone-shaped crown of many-coloured filaments expands from the end of each tube, looking like peacock tail . **Slipper limpets** are often found in clusters on the sand at low tide, but when covered by seawater they too feed using an elaborate ciliary system. The mantle cavity is large, with an inhalant aperture on the left of the head and an exhalant on the right. A mucous filter that traps large particles is continually secreted across the inhalant aperture and periodically transferred to a food pouch on the mantle edge just in front of the head. Medium-sized particles drop out of the incoming current on to the floor of the mantle cavity and are moved to the right where they enter a food groove. A mucous sheet which is spread by ciliary action across the gills, traps fine particles, and is transferred from the gill tips to the food groove, twisted into a string, moved forwards, and periodically engulfed by the radula. **Oysters** use gills to filter the food , their complex stomach contains a rotating structure found in animals, the **crystalline style**, which is unique to ciliary feeding molluscs. It is continuously formed in a blind-ending sac from which it protrudes into the stomach, and cilia in the style sac keep it rotating so that strings of mucus wrap round it. In the acid medium of the stomach, the end of the style slowly liquefies releasing enzymes that digest starch, glycogen and, in some species, cellulose. All indigestible material is eventually discarded through the anus into the exhalant water current. **Oikopleura** is a small tadpole-like animal resembling the tailed larvae of sea squirts. It floats in the open sea and filter-feeds . Its body surface cells secrete a thin transparent envelope, which is separated from the body by movements of the tail. The animal lashes its tail, initially to inflate the 'house' and then to make a feeding current. This enters at the back through two filter windows that exclude large particles, circulates round the 'house' through two fine, conical collecting nets leading to the mouth, and leaves by a hole at the front. The delicate collecting nets filter microscopic particles from the current and pass them to the mouth. At the back of the 'house' is an emergency exit by which the animal can escape, and in good conditions it quickly secretes a new 'house' ,

Strategy to filter food with the appendages - Barnacles lie on their backs enclosed within a box of calcareous plates, the uppermost of which are hinged and open when they are feeding. The widespread **acorn barnacle** Alanus bala-noides has six pairs of fine, branched thoracic limbs, called **cirri**, closely set with **bristles, or setae**, The first three pairs are short and stout; pairs 4-6, which are longer and curve towards the head, straighten and separate as they feed, and are then curled inwards with a grasping movement. Particles caught on their setae are scraped off by setae on the short cirri and passed to the mouth. This movement only catches relatively coarse particles, but while the long cirri are being extended, water rushes in through the fine mesh formed by the overlapping setae of the short cirri, which traps very small particles .Many other **crustaceans** filter-feed while stationary, using **feathery appendages** to make and to filter a water current. Different species use different appendages - **Haustorius arenarius**, a burrowing amphipod creates a feeding current by moving the hindmost pair of mouth appendages, the maxillae, so that water flows in between their inner lobes whose setae trap particles. As the maxillae are raised again, their inner lobes meet and water is forced forwards through setae bordering the outer maxillae lobes thus trapping further particles. The first pair of 'legs' scrape accumulated food from the maxillary setae and pass it forwards to the mouth. From their cover underneath stones, **porcelain crabs** feed by making alternate grasping movements with the third pair of 'legs': as each is extended sideways, its long setae open out into a scoop which retains particles as it is smartly flexed inwards.

1.3 Parental care in animals (by males, by females, by both, by helpers).

A unique social relationship in the animal kingdom is that between parents and off springs. No matter how non- social an animal may be, at least twice in life it has to socially inter act with conspecifics – mating and parental care **(PC)** .It is defined as - form of parental behavior that appears likely to increase the fitness of a offspring . And the Parental Investment **(PI)** is a form of parental behavior that increases an individual offspring's fitness at the cost of the parent's ability to invest in future offspring **(Trivers, 1972).** Parental care takes place:

1. Before Birth

a. Investment in gamete production – female **Katydids** eat spermatophores provided by males have larger eggs which survive better in harsh winter, in this case the male is investing in females gametes.

b. Preparation of the housing -- preparation of nests, burrows, or territories (importance of having a place where broods or eggs can be kept- where young can be left while parents forage or ward off predators) e.g. bees, fish, birds.

c. Care of fertilized eggs -- incubation by birds and reptiles, egg guarding by fish, brood carrying by water bugs and seahorses, protection of nest sites or sites where eggs are laid.

2. After Birth

a. **Provisioning or protecting young** -- provisioning by birds, mouth brooding in some fish, lactation in mammals.

b. **Care following nutritional independence** -- support in conflicts in social primates. Feeding some species of birds after they have left the nest e.g. royal terns or frigate birds.

The forms and means of parental care are as varied as species themselves. Some species, such as salmon lay millions of eggs but provide no parental care, others, such as elephant, gives birth to a single young, shows parental care for many years. There is a great variety of types of parent offspring relationships, fish and amphibians guard their eggs, bird and mammals feed their young ones .It can be of two types (i) one in which the parents and offsprings never come in contact ii) where parents come in contact with offsprings. How common is parental care and who provides it? In terrestrial Arthropods parental care is generally uncommon , if present then is shown more by females than care by males. Scorpions, spiders carry brood on their back, bees and wasps provide shelter and food to their larvae. Among **Reptiles** parental care is uncommon, whatever little care is provided is rendered by females more than males e.g. Crocodilians . In **Amphibians,** 18% salamanders and 6% frogs and toads exhibit some sort of parental care. In this class the parental care is given by males or females. ,e.g. egg attendance and transport, tadpole attendance and transport, tadpole feeding. 25 % of fish demonstrate parental care like -egg guarding, oral brooding, cleaning eggs. Care by male is more common than by female . Most species of birds show **bi-parental** care. The care includes provisioning of female by male prior to and during egg laying and incubation, nest building, incubation of eggs, and feeding nestlings. **100%Mammal** species show care by females (gestation, lactation). Less than 5% show direct male care – male care mostly in monogamous breeders (e.g. tamarins, wolves, naked mole, rats).

Early parental care:

(i) Starts before the baby is conceived in the form of gamete production. Eggs are large and rich in nourishment.

(ii) Birds provide warmth (incubation) to the egg for the chick to develop and hatch properly.

(iii)The construction of nest takes much time and energy of both parents. A pig walks 5-10 kms to look for a safe place to construct a nest and it takes about 10 hours to construct it(Jensen 1993).

Most species that provide little to no care are insects, reptiles, and fish that produce many young .In stable environments when both parents have an equal probability of associating with their offspring then both mother and father provide care; in predictably fluctuating environments when one sex has a higher probability of associating with the young than the other, then that sex provides more care; in fish, this is typically males who defend a nesting territory; in birds, this is typically females except under unusual conditions where females abandon their broods in the care of the fathers and start new broods with additional mates; in mammals, lactation predisposes females to care the most.

Factors affecting parental care

(i) size of the litter or brood: if the size is bigger the parental care decreases ; Lack (1954) proposed that if there is high fecundity , then there is less parental care, and if there is low fecundity then there is more parental care- known as **Lack's Law.** Paradise fishes lay 20-300 eggs they show parental behaviour and anabas lays 1000-3000 eggs and they don't. Elephants give birth to one baby in few years, therefore, parental care or help is extended for a long time. Manatees are also slow breeders, they take their young to water to practice swimming and also support them in water, Grizzly bear cubs are very small- less than 350 grams, and are quite helpless, they need mothers attention for many years.

(ii) **age of offsprings** : younger babies get more parental care than older ones.

(iii) **age of the parent**: younger parents give less care, because they have more reproductive cycles ahead, means they can have more babies and old parents provide more care because they have fewer reproductive cycles (Clutton – Brock 1991).

Types of parental care:

1. Neither parent is involved in care of young : Promiscuity is associated with no parental care, the mating system that typifies reptiles . Most solitary insects , 100 teleost fish species with external fertilization, some amphibians and reptiles, birds showing brood parasitism (e.g. cavity-nesting ducks, cuckoos, cowbird), there is no example from mammals under this category.

2. Both parents involved in care of young : Monogamy is associated with bi-parental care No insects, reptiles or amphibians reported in this , a few fish species (e.g. mouth brooding cichlids) , many bird species (e.g. willow ptarmigan; most song-birds; tri-colour blackbirds), and few monogamous species show this trait. (e.g. gibbons, tamarins, marmosets)

3. Mostly Females are involved in care of young : Wasps , dung beetle, and social bees provision brood cells and defend/protect their larvae , females of about 14 species of teleost fishes with internal fertilization and 24 with external fertilization show parental care, in alligators and crocodiles its generally the female alone that guards the eggs and babies, bird species in which the male has less investment than the female during brood care are red-winged blackbirds and wrens. This is most widely used in animals kingdom. Why females provide so much care ? **According to the investment hypothesis : The f**emale invests so much energy, it would be risk for her to abandon her offspring without providing care, since offspring may not survive. **The**

paternity uncertainty hypothesis says because female is more likely to be parent of offspring than male - male not really gaining from parental care if offspring not his. Lastly there is **association hypothesis,** according to this , the females are more likely to be the parent around during egg laying or birth many a times, due to **internal fertilization** – this situation allows males to leave , females have to care for her eggs . Males physically get separated from progeny. Polygamous mammal species in which only females feed and look after offspring without the help of a male are marsupials, rodents ,ungulates, felids, some solitary primates e.g. orangutan.

4. Mostly Male are involved in care of young : The examples are few in this category , male **water bug** carries fertilized eggs , in fishes the male usually cares for offspring. Parental care occurs in 28% of fish families and among 61% of these the male takes care of the offspring . In about 63 species of teleost fishes , mostly males defend a nesting territory eg **three spined stickle backs**, in **pipe-fish** and **sea horse** female places fertilized eggs in male's pouch, birds living in flooded marshes e.g. jacana , tinamous and moorhens or migratory birds e.g. sandpipers and phalaropes and ground nesting ostrich , however, very few mammals belong to this category . Males of Golden lion tamarin of Brazil are worlds finest fathers. The female generally gives birth to twins, her job is only to feed babies, the rest is done by father alone. He carries them on his back day and night , protects them from heat, rain and predators.

5. Relatives are involved in care of young / alloparenting : Eusocial insects where sisters (full and partial) care for eggs laid by their mother (e.g. bees, termites), no fish, amphibians or reptiles reported, among birds **helpers-at-the-nest are found in** eg **Florida Scrub Jay, green wood hoopoes, white-fronted bee-eaters, babblers, and Mexican Scrub Jay .** In **elephants, wolves, dwarf mongoose, monkeys, lions** the related females , called **aunts** help in feeding the baby , related elephants help each other in acts like while mother drinks at a water hole, the aunt guards the young white-footed deer mouse, prairie dogs, banded mongoose, spotted hyena show communal denning, related females help making a den and can also look after the babies in the den , thief or sneaked suckling is reported in elephant seals .

Care and attachment :

Parental care in parents and development of **attachment** in babies have evolved **simultaneously** thus giving the individuals having those genes a survival advantage. Suppose an adult individual delivers parental care to a

detached offspring, who is constantly straying and is eventually lost, thus losing representation in the next generation. Parents that produce detached offspring would have no survival edge and would eventually become **extinct.** Conversely, if the offspring is born with a bias to **attachment** but is rejected by the parent, it becomes easy prey for predators and strangers. Rejecting parents have then the same fate as detached offspring: Natural Selection will **eliminate** them. Parental Care carries several distinct benefits, and it is curious why it is not commonly found in the entire animal kingdom. An organisms that gives its offspring a tender care would be at a tremendous advantage over another that provided less parental care.

All animals have to face the decision of whether to invest time and energy looking after their offspring or not because the **benefit** is that Young are often helpless and vulnerable to starvation, predation and harsh climatic conditions. Their survival and fitness rely on parents to assess their needs. If the baby survives , the fitness of parent increases and the **costs** are that parents get less time to find food for themselves and get less time to find additional mates. The parents have to put in lots of efforts e.g. a male **mallee fowl i**nvests **5 hours a day for 6 months** of each year to build a huge compost nest of sand and organic material. Each time his mate lays an egg he digs a deep pit to receive the egg and then covers it up, shifting about **850kg** of compost and sand. The mound keeps the egg protected from predators and at a constant temperature. The females show more parental behaviour because (i) their investment is much higher in terms of time and energy (ii) they are sure the offsprings are in fact their own, whereas, males can not be so sure.

parent-offspring conflict :

Freudian theories and theories about socialization of infants (it says humans are born savage and greedy and the parents' job is to teach them to leave their selfish drives and to become a part of society.) However, parent-offspring conflict is not specifically human- it's very widespread in the animal kingdom. Anyone who has looked at parents and offspring in primates has reported parent-offspring conflict of some sort or another.

Trivers (1974) noticed, that the mother, nursing her young, better uses her energy for the production of new offspring, rather than continuing to nurse offspring that are at least partly able to live independently. The offspring, however, does not want to be weaned as it regards its own interests as more important than those of its future brothers and sisters and protests against weaning. In the **carrion crow (Corvus corone)**, for example, conflicts between parents and offspring increase when the juveniles grow up and the parents want to breed again. Then the parents become more aggressive toward their offspring, causing their offsprings' final independence. Other species, for example the spectacled parrot (Forpus conspicillatus), solve the problem by putting their young in a **crèche.** Trivers suggested that evolutionary interests of parents and their young were not same, therefore, causes **parent offspring conflicts**. The theory has been analysed in several mathematical models and have been found logical. Offsprings are expected to gain fitness by demanding more care than the parents are willing to give. offspring will always favour receiving more investment than parents are wanting to give. So there will always be conflict.

Weaning conflict

Think about how in the first stage, the mother is maintaining proximity to her offspring, following it, restraining it from leaving her, and initiating most nursing bouts. In the second stage, the infant becomes more independent and initiates most nursing. In the last stage, the mother trails off efforts to maintain contact, and she stops wanting to nurse. In this later stage, the mother will begin rejecting the infant, gently at first and then more strongly. The infant spends a lot of time shouting and crying. And the conflict about weaning is by no means the only type of parent–offspring conflict

Carrying conflict

Another conflict which is common is over **riding over the mother or carried by the mother**. It is pretty similar to weaning conflict; the mother does everything at first, then less, and the infant gets upset about it. So the parent doesn't want to carry the it and the baby still wants to ride. The young obviously need to learn to walk for themselves .

Temper tantrums

Another manifestation is temper tantrums. As babies get older and the mother begins rejecting the baby, it begins throwing tantrums- screaming and yelling, clinging to arms, pulling her hair etc. This is seen in orangutans, and in many other primates such as chimps, and humans, especially at the height of weaning. There are a few different ways that young use to **manipulate** their parents. In one study Jane Goodall observed that in chimps, the tantrums made the mother tense and nervous and when the infant began throwing a tantrum, she ran to comfort it and then the baby started to nurse.

An infant who has been rejected will begin to act more young and helpless than it really is. Since younger infants need more investment, the baby might trick its parent into giving it more.

C. Predatory strategy :

Stalking, snaring, pouncing, stabbing, tearing, devouring - displays versatility in capturing, killing and eating animal food. Hunters are at large on land, in water and in the air, sometimes also the plants that trap insects and fungi that trap nematodes and other tiny animals in the ground. Herbivores outnumber carnivores in terms of numbers of individuals.

Predator-prey relationships -Natural selection generates competition between predators for food and prey to avoid being eaten leads to an arms race between predator and prey. Every innovation in **weaponry or hunting strategy** evolved by carnivores confers selective advantage on those potential prey able to outwit the predator, and **vice versa**. But animals of all sorts however large, armoured or poisonous, are potential prey and even top predators like **sharks and lions** are vulnerable when young. Since a predator may be someone else's prey, its appearance, structure and behaviour are necessarily a compromise between being effective as a hunter and escaping capture. For example, mantids have spined, raptorial fore appendages with which they grab their insect prey but are themselves eaten by **insectivorous birds**. Mantids that look like **sticks** perfect their **camouflage** by holding the front appendages in an extended position. However, by moving slowly with a swaying gait, as though shaken by the wind, they adopt a **strategy** likely to fool both predator and prey. An animal's role as a predator is modified by its own potential as prey. Thus "**flock feeding" is** a defence against predation, affects feeding behaviour. A peck of wolves can hunt moose , **lions and cheetahs** hunt on small graceful Thompson's gazelles to zebras. While hunting predators miss catching a prey .There would be no long-term advantage to a predator in becoming so successful that it killed all the breeding adults in a prey population. An equilibrium is therefore set up between prey and predator.

Many animals are always in danger of being preyed upon. Therefore, they must have strategies of defending themselves from predators. Animals communicate to their predators about danger of eating them . There are many kinds of defense mechanisms in nature , these include special **warning colours , camouflage , secretion of substances** that deter predators, and others. After receiving a warning message, the predator may leave the scene.

Communication of this type increases an animal's chances of surviving its enemies. The appearance of certain animals and plants assists them in self-defense. Camouflage or **mimicry** are examples of the ways in which appearance helps animals and plants escape detection by predators. Good camouflage allows the animal or the plant to remain out of sight. Mimicry of the colour patterns or shapes of poisonous animals or plants also serves to ward off predators. Many have bold colours - usually a combination of red, orange or yellow on a dark background. These colours are warning colours that transmit a message of danger. Other animals use certain calls to deter predators. Still others may suddenly expose hidden patterns of colour to frighten predators away. Many poisonous animals have prominent warning colours . It is worthwhile for such an animal to advertise the danger. By doing so, it can prevent an attack before it happens. The **lion fish**, a poisonous fish, is an excellent example of warning colors. In addition to its colours, which prevent attack, the lion fish fins fan out to make it look bigger. This adds to the frightening appearance of the fish. The **velvet spider** has typical warning colours among spiders. This spider is very small, but it can be highly poisonous.

All animals need to obtain food. How does communication help animals in their search for food? Many messages are transmitted when animals locate and trap their prey. Some predators obtain food through **trapping and luring strategy**, using the communication channels of their prey to fool it. For example, some predators camouflage themselves in order to sneak up on their prey. Others display their own bodies as tasty food to lure the victim. The prey "reads" the signals sent by the predator, falls for the bait and into the trap.

(i) Strategy to eat sedentary prey:

Colonies of animals produced asexually, whether by budding as in sea squirts, corals and sponges or by parthenogenesis as in aphids, are equivalent to a patch of grass produced by vegetative growth, since the members of the colony are not genetically distinct individuals. The relationship of predators with them is similar to that of grazing animals with grass. Hoverflies Metasyrphus corollae, are **voracious predators as larvae**, each individual consuming a total of **800 to 900 aphids**. Females lay their eggs on aphid-infested plants and the **slug-like larvae** need to do little searching or hunting for food although they can move with unexpected speed. They seize aphids with their mouth-hooks and suck them dry, discarding an empty skin. Colonial marine animals are **'browsed' by slow-moving mollusks** e.g. the shell-less gastropod **sea-slugs**; they either rasp away at their prey or suck out the contents of members of a colony one be with the modified pump-like pharynx. Some of the most brilliantly coloured sea slugs eat sea anemones, corals and their allies. Strategy for a **stationary predator** to grab mobile prey as it passes by. Animals that set up a feeding current, including filter feeders, are in this category, but all feed on tiny food items. Other **stationary predators** deal with prey as large as they e.g. **sea anemone** immobilizes fish, grasped by the tentacles and put it in centrally placed mouth into the capacious digestive cavity. The success of **sea anemones , jellyfish** and all other coelenterates as predators depends on the **batteries of stinging cells** that cover their tentacles.

Snakes have unusual sensory abilities that they can 'taste' air and many can also 'see' heat he flickering forked tongue carries articles into a paired pouch in the roof of the mouth enabling the snake to test for the odour of prey. Pits situated below the eyes of rattlesnakes and **pit vipers** contain heat sensitive membranes on which infrared rays are focused through a pinhole opening. They can detect a rise in temperature of 0.005 °C - caused by movement of a small mouse to within 15 centimeters - and pinpoint the prey's position. **Owls** have acute hearing, their ears are asymmetrical, enhancing their ability to locate mice as they rustle through grass in the dark. **Insectivorous bats** use echolocation to catch moths. **Dolphins** also hunt using echolocation. The whistles they use for communication with each other are just audible to humans but they also broadcast high frequency clicks, which we cannot hear. They emit about one click a second when cruising but this rises to 500 when chasing prey. The sonar beam bounces back to the dolphin that can interpret the echoes in terms of size, position and speed of prey. **Swifts, dragonflies, chameleons and eagles** hunt by sight and many can seize moving prey with accuracy.

Modifications of body shape and limbs of predators are suited to catch specific prey e.g. **seals** are marvels of agility underwater, but leaves them helpless on land, they catch fish with skill but they can not catch a mice. Furthermore, a few predatory species, like the **giant ant-eater**, have become specialists; its long, tubular, toothless jaws and long tongue are ideal for probing the galleries of ant nests and licking up ants, but the tiny mouth, no larger than the diameter of a pencil, is no use for anything else. Such extreme specialists meet little competition for food and do well as long as their prey is plentiful, but are vulnerable to environmental change. For many predators, however, the choice of possible food is large and generalists, like **bears** and **foxes**, are highly adjustable, the **European badger** subsists mainly on vegetable food but digs out rabbit nests and eats the young in spring and summer, destroys bee and wasp nests for grubs and honey in summer, and searches beneath turf for insect larvae in late summer and autumn.

Four factors influence what a predator eats: **availability, palatability, accessibility and profitability** or return for effort . **Termites** are eaten by **kites, hornbills, rollers and bee-eater** when winged reproductive swam from subterranean nests, but for most of the year they are not available. The abundance and availability of prey fluctuates and the efficiency of exploitation is improved by the habit of food storing. Wolverines of the taiga of North America and Eurasia, cache food in times of plenty to tide them over the winter when deep snow makes hunting difficult. Red foxes hunting in stubble fields catch and bury as many mice as possible in the twilight hours most favourable for hunting, but eat them within 24 hours. In both instances, hunting is intensive when conditions are optimal and the food is eaten later when hunting is not possible.

(ii) Strategy to catch a moving prey

A *Chameleon* on a branch stalks its, insect prey slowly, foot over foot, with economy of effort. The grasping feet have ridged, non-slip soles and the prehensile tail is coiled around the branch for added stability. The turret like eyes can swivel independently of each other through almost 1800 in the vertical and longitudinal planes. Once within striking distance of prey, contraction of the tongue's muscles fires it along the narrow, tapering bone that supports it, an operation that takes only 40 milliseconds. An indented, sticky pad at the tip of the tongue picks up and hauls in insects from distances of over half the length of the chameleon's body. **Starfish** also move slowly but employ strength rather than speed when the encounter a bivalve on the sea-be!y They crouch over their prey and pull at the shell valves with the tube feet, generating a force of up to three kilograms. Within five or ten minutes the valves have separated by one-tenth of a millimeter, sufficient for the starfish to insert its extruded stomach and start digesting the soft body.

To get within striking distance of prey, hunters demonstrate a multiplicity of adaptations for stealth and speed. **Fishing herons** prowl delicately through shallow water, lifting their feet to minimize water disturbance but snap quickly at fish. **Eels** shelter immobile in crevices ready to make a lightning grab at passing fish with their massive jaws; and *Caprella***,** a crustacean waits in ambush on hydroid coelenterates ready to pounce on any small animal that swims near. **Cats,** too, show a combination of stealth and speed once prey is sighted. (small wild cats, like domestic cats, make a subtle, low-bellied run, slowly stalk forward as they approach the prey, then wait in ambush until it's the right moment to pounce. The musculature and build of **lions**, with power concentrated in the strong hindquarters, are adapted for a rapid, quick lunge from an ambush, but in contrast, cheetahs, like dogs and wolves, are long-legged and slender, with the stamina for a long chase that tires the prey

The act of killing prey ranges .The neckbite is the characteristic killing method of Carnivores, and small **cats** grab mice with the paws and bite the neck just behind the head with the canine teeth, forcing apart the neck vertebrae and breaking the spinal cord. **Lions** and other large cats pull prey down with their forelimbs, keeping their hind feet firmly on the ground to provide stability during an ensuing struggle. **Foxes** have a characteristic **'mouse-jump'**, bringing both forepaws and the nose forcefully down on the prey and, like many other Carnivores shake their prey . Speed is the essence in securing prey with **teeth, beak or claws .** Exotic weapons have been evolved for immobilizing prey, such as the **high voltage discharges** from modified muscle blocks with which **torpedo rays** stun other fish. **Poisons** too are part of the armoury of predators. **Spiders and centipedes** have poisonous fangs, **jellyfish** inject poison from thousands of **nematocysts** on their tentacles, and **wasps** twist their abdomens in all directions to grab their struggling prey with their stings. The most sophisticated poisons are with the vipers and their allies. A few predators use **tools** to capture food. **Chimpanzees** 'fish' for termites by poking sticks into termite mounds, and the **Galapagos woodpecker** finch uses a twig or thorn held in its beak to extract insect larvae from their tunnels in wood. **Archer fish** use water as a tool by accurately spitting droplets for distances up to 10 times their own length so that insects are knocked off overhanging vegetation into the water. Many **spiders** make a trap nest for their prey.

How can fish locate their prey in the dark depths of the ocean. They use glow-in-the-dark bait! The **angler fish** has a "hook" on its back. One of its dorsal fins is very long, reaching forward in front of its mouth. At the tip of the fin there is an appendage that looks like a **glow-worm**. When the angler fish shakes this "hook," the "worm" wriggles in the water. Other fish in the area approach, and the angler fish swallows them. **Flashlight fish** have a piece of glowing "bait " near their eyes or deep in their mouths. This bait is visible only when the fish opens its jaws. Small fish, worms and crabs passing by swim towards the glowing light, taking them as food. **Female fireflies** of certain species use their light signals to attract a meal as well as a male. After luring a male and mating with him, the female firefly changes her pattern of signals. She uses the signals of another species and thus fools the males of that species into thinking she wants to mate with them. When they come close, she eats them.

(iii) Strategy to use sonar to catch food :

Bats and whales use sonar to catch a meal. How do bats locate their prey? And how do moths succeed in "jamming" the communication channels of the bats that hunt them? Insect-eating bats hunt for food at night using built-in **sonar** . This sonar helps them learn about the location and movement of objects in their area. Thus, they are able to find and catch insects as small as the head of a pin. Bats also eat moths. But some moths can detect the ultrasonic sounds made by the bats and take action to escape detection . A moth that detects an approaching bat will change its flight path very suddenly. Some species of moths can even answer the sounds that the bats make. They respond with a sound that mimics a bee. The bat do not eat bees.

(iv) Cooperative hunting strategies :

Social animals have been able to develop **cooperative hunting strategies** which not only increase their efficiency in locating and catching prey, but also enable them to overcome and eat prey much larger than themselves, as well as improving their chances of defending their catch against other predators. Since the members of social groups are usually related to each other, they have a shared genetic investment in the next generation and there is selective advantage in cooperation rather than competition. The adult females in a **lion pride** cooperate in driving and ambushing prey. If the prey is small, it is shared out according to a dominance hierarchy based on size, so males eat first, but large prey is gobbled communally without competition. How can social predators hunt more efficiently ? By using **a) strategy to hunt together** . Animals that hunt in packs communicate rapidly and transmit very clear messages during the hunt. They coordinate all the stages of the hunt: the ambush, the assault and the chase. They use forms of communication which can not be understood by their prey. Cooperation and good teamwork thus help the pack to obtain food. Lionesses hunt together . Male lions don't usually hunt? The lionesses, do all the hunting. They work together, cooperating with one another during the hunt. They use communication in order to hunt as a trained team. They sneak up and surround a herd of peacefully grazing animals, like gazelles or zebras. One lioness then breaks into a run, causing the entire herd to flee in fear.

Meanwhile, the other lionesses hide in the bush. One of the frightened animals runs right into their ambush and is captured. Although the lionesses hunt the food, the males eat first. Only when they have had their fill do they let the females and the cubs eat. Hunting in group has an advantage that one lioness alone cannot catch, kill and protect her prey. For example, a pack of hyenas may try to steal her meal. But a pride of lionesses can protect its food from thieves to make it available for their cubs.

Strategy to reduce competition for food- in social animals that feed together, expression of dominance are ritualized to reduce/resolve competition for food without dispute or aggression. **Social hierarchies** within groups are called **peck-orders.** Their primary significance is in social relations and mating rights, but they extend to feeding. Availability of food is the major factor limiting the size of animal populations. Predator population depends on prey availability. An important factor influencing feeding strategies is minimizing competition with other species with similar requirements. **Three species of leaf-eating colobus** live in the forests of southwestern Ghana but competition for food is minimized by ecological segregation ; the **western red colobus** feeds in the **upper and middle zones of the canopy**, the **black and white colobus in the middle and lower**, and the **olive colobus feeds only in the lower part of the tree**. Even if their food preferences are similar, they are unlikely to compete, and hence can spend proportionately more time feeding and less time aggressively interacting with each other.

All the adults in a pack of **African hunting dogs** embark on a hunt, each following a different antelope in a herd, but they eventually join the one that is closing in for a kill and cooperate in cornering and bringing down the prey. Hunting dog packs are more closely related than lion prides and there is little evidence of a social hierarchy in hunting or eating; there is no quarrelling over a kill and the young feed first. The largest hunting groups are those of **African driver ants** and the **army ants** of Central and South America, which number hundreds of thousands of non-breeding workers, all the offspring of a single queen.

2. Parasitic feeding strategy

An organism that derives food from other living organism (host) by harming it is a true parasite. They are of two types 1) **ectoparasites** that live out side the host's body on the skin, in the fur or feathers and 2) **endoparasites** that live inside the host's body – in blood, muscles, alimentary canal. Parasitism has evolved independently in many different organisms as a strategy for establishing a permanent and secure relationship with a source of food, and both animals and plants function as parasites and as hosts.

A mosquito that settles only briefly for a blood meal later feeds else where is not a parasite . Neither is a spur-winged plover picking food fragments from the teeth of a crocodile but the lice in hair are parasites for they stay with him and depend on his blood for food; so are the tapeworms in intestine, *Opalina,* lives in the rectum of frogs, or the flatworm, *Oculotrema,* lives in the eyes of hippopotamuses and feeds on their tears, lampreys eat the flesh of their hosts. Limpet-like snails, *Thyca***,** live within the feeding grooves of a starfish common in the Indo-Pacific region. They are tiny snails, bright blue like their starfish hosts. They have neither radula nor jaws, but the tissues around the mouth form a sucker' from the centre of which the proboscis is inserted into the soft tissues of the starfish to suck fluid food. *Thyca stellasteris,* has a small proboscis, three times as long as the body, is kept permanently plunged into its host, and the foot is rudimentary. The gut is small but the salivary glands are enormous, a common condition in parasites that suck fluid food such as blood .

Other gastropods, such as *Enteroxenos,* are internal parasites of **sea cucumbers**. Although the larvae are like those of other molluscs, with shell and foot, adults lose all resemblance to snails, become worm-like and lie in the body cavity of the host absorbing nutrients. Parasitic barnacles*, Sacculina***,** have evolved a different strategy for feeding parasitically within crabs. They can be seen protruding from **crab's abdomen**. The adult Sacculina becomes a tumor-like central mass of cells with numerous branching processes that ramify into every part of the host's body absorbing nutrients. Internal parasites such as Sacculina absorb large quantities of nutrients from their hosts but do not destroy them. In contrast, the larvae of ichneumons, such as *Promethes sulcato* feeds on the pupae of *Melanostoma scalare* and other small **hoverflies**, gradually consume their hosts, leaving the vital organs till last. The parasite's supply of living food is assured but by the time it pupates, the host is an empty shell. Such unusual parasites, which eventually kill their hosts, are known as **parasitoids.**

Parasitism profoundly affects the shape, size, structure and activities of animals.

They need techniques for locating their hosts but once they have found them, their food supply is assured and their resources can be devoted to reproduction. As a consequence parasites have tended to lose attributes necessary for active life, but their reproductive capacity is enormous. *Thyca* snails show many features common to animals that live parasitically on other animals. They are (i) unobstructive in size, shape and colour, have a means of attachment and mouthparts modified for piercing and sucking.

Internal parasites, however, such as Sacculina are quite unlike related free-living species. (ii) *Sacculina* larva develops a dart-like structure through which it gets injected into the crab's body. (iii) All the resources drained from the host are converted into the next generation of parasites. For instance, a single roundworm, *Ascaris lumbricoides*, in the human small intestine contains about **27 million eggs**. (vi) furthermore, the life cycles of many of the most successful parasites, such as the malarial parasites *Plasmodium* and the flukes responsible for Schistosoma, involve episodes of asexual reproduction,(vii) adaptations that increase the chances of fertilization are varied and ingenious. Each segment or **proglottid** of a mature **tapeworm** contains a full complement of male and female reproductive organs so that, although cross-fertilization is desirable, reproduction is possible when the host contains only one tapeworm. In contrast, female *Schistosoma* lie within grooves on the males in permanent copulation. In certain **parasitic crustaceans**, which attach themselves as larvae within the gill chambers of **prawns and crabs** and suck their blood, the first larva to take up residence becomes a female and later arrivals develop into males. Young females placed with mature females become males, and young males placed in the gill chambers of uninfected crabs change into females. This labiality of sexual character, ensures sexual reproduction between any two individuals, is carried a stage further in some parasitic barnacles and gastropods where the male becomes parasitic on the female and equivalent to a testis in a hermaphrodite individual (viii) successful parasites live in equilibrium with their hosts and do nothing that provokes a violent reaction. **Amoebic dysentery** is the consequence of damage to the lining of the large intestine caused by the feeding activities of a protozoan *Entamoeba histolytica***.** 80 percent of the estimated 400 million people who harbour *E. histolytica* suffer no ill effects. (ix) parasites exhibit varying degrees of intimacy with their hosts and dependence upon them. **Tapeworms** are never found free-living; if the host dies tapeworm dies too.

Eggs of human **hookworms**, which are passed with faeces, hatch into free living larvae that feed on soil bacteria. Similarly, **larval fleas** are free-living, feeding on decaying animal and plant material, usually in the nest or burrow of the animal that serves as host for the adult. Conversely, the **larvae of fresh-water mussels** are parasitic on the **gills of fish**. Their toothed bivalve shells close on the host tissue that reacts by enclosing each parasite in a vascular cyst. The larval mollusc has no gut but the cells of its mantle digest and absorb the host gill tissue. Many insects, especially **flies and wasps**, also have parasitic larvae that become free-living adults. Larvae of the *Cordylobia anthropophaga* (the specific name means **'man-eater'**) burrow into human skin forming open tumors, the larvae feed on human . When fully fed they drop out, pupate in the ground, and turn into flies. Other parasites, such as the protozoans causing malaria and sleeping sickness, are parasitic throughout their lives, although the complete life cycle involves more than one host.

Vectors - A female human **botfly (** *Dermatobia hominis***)** catches and holds a mosquito or other biting fly with her legs, fixes a batch of eggs to it. When this mosquito takes a blood meal the eggs of botfly hatch on human skin and the botfly larvae enter the puncture made by the mosquito. The botfly is thus using the mosquito as a **vector** for transport and transmission to another host. Many blood parasites have resolved the problems of host location by parasitizing mosquitoes and other blood-sucking invertebrates that serve as vectors. One of the nematodes parasitizing man is *Wuchereria bancrofti* causes **elephantiasis** . Adult nematodes live in the **lymph glands** and ducts, and females produce numerous, minute larvae called **microfilariae**, which move into the peripheral circulation at night when the vectors, various species of *Culex* **and** *Anopheles* mosquitoes, are active. Microfilariae taken into mosquitoes with a blood meal penetrate the gut wall and eventually move to the proboscis sheath. When next the mosquito takes a meal of human blood, larval nematodes leave the proboscis and enter the feeding puncture. **Nematodes** are able to penetrate the tissues and cells of other organisms including plants. A variety of species cluster around plant roots sucking cell sap. Larval females of *Heterodera* invade the **roots of potatoes** and other plants, and move between the cells to a group of phloem cells from where they suck a continuous flow of sap.

Parasites and food chains -The neatest strategy evolved by parasites for ensuring entry to an appropriate host is exploitation of their feeding habits, and many internal parasites use as food two or more members of a food chain.

Renicola is a parasitic flatworm, or trematode, that uses three different hosts during its life cycle: shearwater (bird), sardines (fish) and tower shell (mollusk) . Adults live in the kidneys of shearwaters that pass eggs in their excreta, shear-waters lead a wandering life out of the breeding season, and are believed to excrete little through their kidneys when away from supplies of fresh water. The eggs are shed in coastal waters, they settle on mud banks where **deposit-feeding** tower shells are found. The eggs hatch inside the snails that release cercariae into the sea along with their eggs in the breeding season. The cercariae swim upwards and, when eaten by **plankton-feeding sardines**, encyst until such time as the sardine is eaten by a shearwater.

Tapeworms have proceeded further in their dependence on host animals and exploitation of their feeding habits. The adult pork tapeworm *Taenia solium* is attached to the wall of the human intestine by the scolex, it has no digestive tract but absorbs simple food units like monosaccharide sugars and amino acids, selectively from the host's gut contents. Ripe proglottids containing fertilized eggs are shed by the tapeworm and passed in the host's faeces. If in-gested by a pig along with its food, the eggs hatch, bore through the intestine wall into the blood system and finally settle in muscle as a bladder worm, within which an invaginated scolex develops. When inadequately cooked pork is eaten, the scolex evaginates and attaches to the wall of the intestine.

3. Saprophytes :Eating dead plants and animals

Thus far we have been concerned with the different ways in which organisms feed on live plants and animals, but this chapter is about **saprophages or saprophytes** , which eat dead organic material. Dung is not the only organic refuse that is disposed of promptly in a natural ecosystem. The annual accumulation of fallen leaves and other dead vegetation in gardens, fields and woods soon disappears. We take this for granted and rarely question what happens to it. Animals die, yet we rarely counter their corpses.

All ecosystems, whether grassland, forest, lake or sea, are dependent on the activities of decomposers that convert dead plants and animals or their waste products into simple, **inorganic compounds**. The **decomposer** food chain is the channel through which nutrients are recycled back to green plants. Land plants consist largely of woody material that supports leaves in the air and little of their total mass is consumed while alive; as much as 90 to 95 per cent of primary production of forests is ultimately consumed by decomposers rather than herbivores. Since the bulk is eaten when **dead, the decomposer** food chain is the major pathway of energy flow in most terrestrial ecosystems. Decomposers release and use chemical energy from dead plants and animals but eventually all is dissipated as heat.

In countries with a native fauna of large **herbivores** producing quantities of **moist dung**, there are **dung beetles** adapted for exploiting it as a food source

In **Africa** alone there are more than **two thousand species of such beetles**. They are varied and abundant: more than **seven thousand individuals** have been counted in a single mass of **fresh elephant dung**. Their response to the odour of faecal gas is prompt and by the time buffalo dung hits the ground, beetles are moving towards it. Adults squeeze and rub dung between their mouthparts, extracting juice and a fine paste of small particles. Most species excavate tunnels beneath dung and carry lumps, freed of seeds and other large particles, down into the soil as food for their developing larvae. Others carve portions from dung masses and move these some distance away before digging a chamber and burying the dung on which the female has laid an egg. Some butt lumps of dung over the ground but others knead it into a smooth ball and roll it with the hind legs while walking backwards on the forelegs. Dung beetles thus fragment and disperse dung, making it available to soil microorganisms, as well as eating much themselves. Within a day or two, nothing remains above ground but a few wisps of fiber.

Not all decomposers feed in the same way and two distinct operations are usually involved in the breakdown of dead material. Relatively large animals, such as **wood-boring beetles** or **carrion-feeding hyenas**, fragment and ingest dead organisms. This opens them up for bacteria and fungi that also feed on faeces. Thus the final stages of decomposition are effected by **microorganisms** but accelerated by the feeding activities of larger decomposers. Unlike herbivores and carnivores, decomposers are rarely restricted to food organisms of a single taxonomic group let alone a single species. **Scavenging molluscs** and **crustaceans** eat **rotting vegetation** and **carrion,** while **deposit and suspension-feeders** utilize any fragment of organic material.

Leaf litter- It is an everyday observation that dry, dead leaves remain intact for long periods of time and it is only after wetting that they start to disintegrate. At the season of leaf fall, a garden pond or woodland stream has a massive input of dead vegetation which is exploited by fish, crustaceans and many other invertebrates, as well as providing a substrate for bacterial and fungal growth. Water softens leaves and leaches out

tannins and other toxic substances making them palatable to invertebrate animals and accessible to microorganisms.

Woodlice, snails, millipedes and some species of **earthworms** play a major role in fragmenting leaves on land, and most decomposition takes place actually in the soil. **Saprophytic fungi** quickly colonize and decompose fragments of plant material, absorbing soluble sugars and liberating digestive enzymes at the tips of growing hyphae. Cellulose is attacked rapidly but as the chemical structure of the leaf is broken down, fewer and fewer sorts of fungi can utilize what is left as food. Much of the lignin in leaves is incorporated into humus where it is slowly decomposed by soil fungi. Some **saprophytic bacteria** use the sugars of cell sap leached from leaf fragments in wet soil or in faeces; others use cellulose and other carbohydrates. Together with soil fungi they break down leaf tissue into inorganic compounds that are then available as nutrients for plants.

Dung beetles are not the only insects that use dung as larval food , several flies also develop in cattle dung, e.g. yellow dung flies .Females of a hoverfly lay their eggs on vegetation overhanging cow-pats. Newly hatched larvae drop off, seek a crack in the dried outer surface of the dung and penetrate the moist mass beneath. Faeces on the ground or incorporated into the soil are a rich source of nutrients not only for fungi and bacteria, but also for a variety of animals. **Pot worms** thrive in forest litter provided it contains caterpillar faeces; in turn their faeces are eaten by earthworms whose casts provide a habitat for certain beetles. Faeces of the aquatic crustacean, *Asellus aquaticus***,** contain fungal spores that colonize plant debris. Their larvae eat the partially decomposed plant material but do not survive if reared in sterile cultures without adults. Animals as diverse as **koala bears** and **termites** acquire their **gut microorganisms** as well as nutrients by ingestion of faeces, and **cubs of the spotted hyena** eat fresh herbivore dung, to acquire vitamins otherwise absent from their diets. **Honeydew** is **bean aphid faeces** but consists largely of sugars; plants heavily infested with aphids quickly become smeared with sugar that is colonized by moulds. Honeydew is an important source of high-calorie food for **hoverflies, wasps, bees**, but above all ants, especially in drought conditions when nectar supplies are reduced.

The fate of dead animals -The speed with which **vultures find carrion** is proverbial. When searching for food they fly high, their eyesight is keen and they locate food by sight. Several species of vulture occur together in the East African grasslands, but reduce competition by feeding on different components of carcasses. **Griffon vultures** eat mainly **soft meat** from large carcasses; other species eat more skin, tendon, bone or harder meat. When feeding they delve deep into carcasses but since the heads and necks of most species are bare, clogging of feathers with blood is kept to a minimum. **Lions and hyenas** run quickly to where they see vultures land and have little trouble driving them from a carcass. **Hyenas**, although renowned as **scavengers** are efficient **predators**. Their massive jaws are worked by powerful muscles that exert the force for their broad, conical premolars to crush the largest bones and for their bladelike teeth to tear the toughest hide and tendons. The feeding activities of **hyenas** and other vertebrate scavengers not only accelerate decomposition by opening up a carcass for **microorganisms and fly larvae**, which feed by discharge of digestive enzymes, but also speed up the recycling of nutrients incorporated into bone. On land, decomposition by bacteria or invertebrates is slow once a carcass dries out, and the activities of burying beetles are an adaptation to extend the period when a carcass is moist and therefore accessible. In aquatic environments however, decomposition is rapid. Few animals thrive feeding on organic material discarded by man e.g. **carrion-feeding fly larvae, larvae of owl midges, hoverflies and winter gnats cockroaches and crickets, brandlings and other earthworms, roundworms.** People tolerate animals that remove and dispose off dead material which otherwise becomes a source of unpleasant smells and infection. In India the cows are tolerated on roads because they remove rubbish by feeding on it similarly **spotted hyenas** are permitted to roam the streets of *Harare* **in Ethiopia** as they are the official street cleaners, receiving a small but regular food supply and as a consequence disposing of all edible rubbish. Much of the debris deposited by the tide is organic and the seashore provides rich food for **scavenging crustaceans** such as crabs and **sand hoppers**. Inter tidal isopods, **Idotea**, feed on material of animal and plant origin by successively scraping and biting, scraping and chewing, using spines on the mouthparts and incisor and molar processes on the mandibles.

(4) Miscellaneous

A. Commensalisms :

Many insects exploit the feeding activities of others without depriving them of food - **ants** lap the juices exuding from leaves chewed by **caterpillars**; **butterflies** suck plant sap oozing from **grasshopper** damage; and a variety of **moths** and **flies** feeds on blood leaking from **mosquito** puncture .The dorsal fin of **remoras** is modified into a powerful **sucker** with which they cling to **sharks**. They detach themselves to scavenge fragments of their host's food then reattach to the same or another shark, the **damselfish Amphiprion** lives among the tentacles of giant **Stochactis** sea anemones and feed when their coelenterate hosts feed , a crab spider **Misumenops nepenthicola** lives on a silken scaffolding in the pitchers of *Nepenthes gracilis* in Borneo and catches some of the insects that fall in; if threatened it retreats into the digestive fluid at the base of the pitcher but is unharmed by it. **Hermit crabs** are associated with a variety of commensals that live on or in their adopted shell, a polychaete worm, *Nereis furuta,* lives in the apex of the shell of *Buccinum* .

Birds are opportunist feeders and can often exploit the activities of other animals including man - gulls follow the fishing boats. The feeding efficiency of **cattle egrets** is enhanced by their association with cattle or other large ungulates. Each bird walks near the head or at the side of a grazing cow, catching insects, amphibians and reptiles flushed by its movements. They also take ticks that have fallen to the ground and may take flies from the sides of cattle but there is no evidence that they are instrumental in ridding mammals of parasites.

B. Symbiosis/ mutualism

Mutually beneficial relationships between organisms - known as symbiosis or mutualism includes the most complex and intimate feeding associations known. The participants are unrelated and in different trophic categories but many have evolved such interdependence that the relationship is obligatory. The most familiar symbiotic relationship between producers and consumers is that between **flowering plants** and the **insects** that pollinate. It is at its most complex in **fig plants**, each species of which is pollinated by just one species of tiny **chalcid wasps**. A fig encloses male and two sorts of female flowers. Female wasps, each only two millimeters long, burrow into the cherry-sized figs of *Ficus pertusa* in Costa Rica, after shedding their wings . They pollinate seed flowers, lay an egg in each gall flower and then die. Within the airtight fig, seeds ripen in the ovaries of the true female flowers and wasp larvae develop in the gall flowers. Wingless males emerge first, locate unhatched females, mate with them and then make an exit hole in the fig although they often die without leaving. The raised oxygen level triggers the opening of male flowers and emergence of females that are attracted to the male flowers by their scent. They collect pollen and then leave through the holes bored by the males to seek another tree in the right stage of the pollination cycle. **Scavenging ants** remove dead wasps from the fig, which finally ripens to be eaten by **howler monkeys** and other fruit-eaters that disperse the seed.

Some fruits are adapted for dispersal by particular fruit-eaters, but a plant dependent on just one species of fruit eater is highly vulnerable. A tree *Calvaria major* was once abundant on Mauritius but the few surviving trees are more than 300 years old. They produce apparently fertile seeds but these are enclosed in a thick, hard seed coat which must be broken if they are to germinate. This has been achieved by force-feeding the fruits to turkeys whose muscular, stone-filled gizzards abrade and crush the seed coats. The only native bird that achieved it in natures was the **dodo** (*Raphus cucullatus), which* became extinct about 300 years ago - the age of the surviving C. major trees. Extinction of the dodo threatened the survival of the tree as well.

Lichens are intimate associations between **algal cells** and **fungal hyphae**. The fungus gains oxygen and carbohydrates and the algae acquire water, mineral salts, protection from drying out and a means of attachment to the substrate. **Nodules** on the roots of **beans** and other **legumes** are caused by bacteria of the genus *Rhizobium* that can exist indefinitely as saprophages in the soil but are able to fix nitrogen within plant cells. This is a mutual enterprise for neither Rhizobium nor the legume alone can synthesize the enzyme used in the process of nitrogen fixation or the pink pigment, of unknown function, which gives the tissue of fresh nodules its characteristic colour. *Mycorrhizae* are associations of fungi with plant roots. The roots of **eucalyptus and pine** trees are clothed with a mat of fungal hyphae, which penetrate between the cells. The trees use the inorganic nutrients absorbed from the soil by the fungus that uses the carbohydrates manufactured by the tree. **Cleaning** another animal by eating its parasites is the commonest symbiotic relationship between consumers. How can a giraffe get rid of the ticks behind its ears? And what does a crocodile do to remove a leech that is stuck deep inside its throat? There are animals that provide "cleaning services" for other animals. Giraffes, antelopes, zebras, rhinos and other African animals recognize ox peckers and allow these birds to feast on parasites that suck their blood. The ox peckers spend most of their lives on the backs of their hosts. This is where they sleep, court and mate. They even pull out hair from the hides of their hosts and use it to line their nests. Ox peckers and ungulates cooperate in other areas as well. When an ox pecker sees a predator approaching, the bird sounds an alarm. If its vegetarian host ignores the warning and continues to graze in peace, the bird sound an emergency alert. It will chirp loudly while jumping up and down on its host's back or even pecking its head.

A number of birds remove parasites from ungulates . **26 species of fish, six species of shrimps and a crab** are known to be involved in **cleaning symbioses** with fish, most of them in clear, tropical seas. The cleaners are brightly coloured, contrastingly patterned and often behave conspicuously. Their **customers** actively solicit removal of parasites, bacterial growths and diseased tissue . **Cleaner fishes** are commonly seen around **eels**. The **Pederson shrimp** of the Bahamas has a transparent body strikingly striped with white and spotted with violet , as a fish approaches, it moves its long antennae. Prospective **customers** stop and present parasitized area for cleaning, allowing the shrimp to explore the gill cavities and mouth and to make minor incisions with their claws to remove parasites. What does the crocodile do? It opens its jaws to allow the crocodile bird or tooth pick bird to jump inside its big ferocious mouth. This fearless bird cleans the crocodile's mouth of parasites and leftover food.

Most **honey guides** eat not only insects but also vast quantities of dry wax that they are able to digest with the aid of wax-splitting bacteria in their digestive tracts. However, they cannot open bees' nests and depend on *Mellivora capensis*(**ratel)** or men to gain access to wax . Ratels have powerful claws with which they break into nests to eat' grubs and honey, their exceedingly tough skin being impervious to bee stings. Two species, **Indicator and variegatus**, have earned the reputation of honey guides. They become excited and noisy when they see animals associated with their food and fly ahead of them, only stopping and becoming quiet within sight and sound of an active bees' nest. There is no evidence that the birds find a nest and then lead honey-thieves to it. Once the raider has finished eating and moved on, the honey guide flies down, often joined by others of the same or different species, and feasts on the wax.

Female **ambrosia beetles** carry **fungal spores** from tree to tree in special pockets in the exoskeleton of either the head or thorax, and they and their larvae feed on the fungal mycelium that develops in their burrows. Similarly, the developing larvae of giant wood-wasps eat their burrows along wood softened by growth of a fungus introduced by the female when she lays her eggs. The fungus-garden termites of Africa and Asia and the leaf-cutter ants of the Americas grow, propagate and harvest fungus for food and can fairly be described as cultivators. Leaf-cutter ant ,cut leaf fragments and carry them a lot like parasols back to their sub terrain nests. The leaves are carefully chewed to soften the tissue and release nutrients. Fragment of fungal mycelium are 'planted' fresh leaf material and 'fertilized' with liquid faeces. The fungus digests cellulose but not protein and the faeces contain enzymes that release nitrogen for fungal growth. As the mycelium spreads. small white swellings develop on its surface and are harvested, eaten and used as brood-food by the ants. Each queen that leaves to found a new nest carries a pellet of fungus in a pouch below her mouth. Leaf-cutter ants use their fungus to convert freshly cut plant material, especially its cellulose, into a nutritious food. They prevent it from fruiting and inhibit growth of alien fungi, although once a nest is abandoned, mushrooms sprout from the mycelium.

Worker termites use their faeces, which contain lignin, as a substrate for fungal growth, building up masses of faecal pellets to fit the chambers of the nest. The compact fungus combs produce swellings that the workers eat and regurgitate, partially digested, to the king and. queen, nymphs and soldiers. Early in the rainy season, *Odontotermes* detach the outer layers of some fungus combs and spread them on the ground above their nests where, after a few days, a carpet of small, edible mush-rooms, *Termitomyces,* develops. When these have withered and released their spores, the termites collect vegetable debris, presumably contaminated with a hybrid mixture of spores, and use it to renew their fungus combs. The fungi termites cultivate are known only from termite mounds, and the termites are dependent on them to make efficient use of . wood as food. Termite fungi fill exactly the same symbiotic role in the nutrition of fungus-growing termites as flagellate protozoans do for dry-wood termites.

C. **Courtship feeding** is primarily a strategy for appeasing a potentially aggressive individual. Male **spiders** run the risk of falling prey to a female as they advance. One-way of averting this is to present her with prey and copulated while she is intent on eating. Most **empid flies** are carnivorous and cannibalism of males by females is postponed by a food gift. This persists in a nectar feeding empid fly, *Hilara sartor,* as ritual presentation of an empty box of silk similar to that in which other species wrap their prey. However, a protein meal is essential in many insects for egg maturation , female **mantids** that start eating their mates at the head end while they are still copulating.

The male shrike offers gifts of food to his mate, but he gives his gifts in a very different way. The shrike catches and eats animals such as insects, small reptiles, mice and tiny birds. However, instead of eating his prey right away, he "stores" it by spearing it on a sharp object. He uses things like thorns or needles from acacia or date trees. He will even use sharp objects such as barbed wire to spear his food. During the breeding season, the male catches even more food than usual, and puts it on display in obvious places. In this way, he tries to lure passing females. The shrike's value is measured by the number of skewers he puts out. If he has a lot of skewers, the females know that his territory has plenty of nutritious food. The female shrikes are more attracted to "good providers". The shrike who can offer the most skewers is most likely to attract a mate.

The male pied kingfisher catches the fish he eats in a very special way. He hovers above the water until he sees a fish swimming by. Then he dives straight down into the water and grabs the fish in his sharp bill. He eats most of the fish himself, but gives some to his mate as a food offering. In this way, the kingfisher shows that he is a skilled fisherman who can provide food for his mate and their offspring. These food offerings also give the female the extra energy she needs for raising her young. It just goes to prove that the way to a female's heart is through her stomach.

D. **Parental feeding -** provision of food for the young is another way in which parents protect their genetic investment. Adults of **birds** that remain in the nest after hatching have a stereotyped response to a gaping mouth with a swollen yellow rim - they cram it with as much food as it will accept. **Cuckoo** nestlings are fed by foster-parents because they provide this simple sign stimulus and Nestling **herring gulls** respond to a contrasting spot on a long, thin beak, but especially to a red spot on a pale beak (which adult herring gulls have). Parent birds are kept constantly busy feeding a brood of nestlings and indeed clutch size is adjusted by natural selection to produce the number of young that the parents can on average provide food for.

Female **spider-hunting wasps** stock their burrows with enough spiders for each larva to complete its development. In contrast, some digger wasps, open their burrows daily and feed the developing young according to need. **Social wasps** feed exclusively on nectar and other sweet fluids but they capture caterpillars and other soft-bodied invertebrates, chew them well and feed 'hamburger' pellets to their helpless larvae. seed-eating **weaver finches**, fruit-eating **manikins** and nectar-feeding **hummingbirds** collect insects for their young. The easiest way of transporting food is in the stomach and there is the added advantage that it is regurgitated with enzymes that aid digestion by the young. The food may be little changed such as the fish a **heron** feeds to its nestlings, but common diving **petrels** regurgitate a red, creamy ribbon of food like toothpaste from a tube. Many **storks** regurgitate their food on the ground for the nestlings to pick up but young **pelicans** plunge shoulder deep into their parent's gullet to feed. Another evolutionary strategy for maintaining a constant supply of fresh, nourishing food for helpless young is the secretion of nutrients by the female. **Mammals** by definition do this, the name being derived from the Latin word mamma*,* meaning breast. A nursing female can draw on her bodily reserves for milk formation so that provision for her young is unaffected by day-to-day fluctuations in the quantity or quality of food available to her. Pigeons' milk is produced in the crop of both sexes and regurgitated to nestlings. Like mammalian milk it is derived from fatty cells shed from epithelial, or lining, tissues and its production is under hormonal control. Nestling domestic pigeons are fed solely with 'milk' for five days and then with a mixture of milk and regurgitated, and hence softened, grain. The special brood-food of honeybees is somewhat similar, being produced in the pharyngeal salivary glands of young workers.

Parental care occasionally involves the **young eating their mother.** Bizarre though it seems, this is a practical arrangement whereby the next generation utilizes parental resources to the maximum. Females of a **spider***, Amaurobius terrestris,* lay eggs in burrows . The young share their mother's prey until they have reached an advanced stage of development but early in the winter she dies and they feed on her body. Ribbon worm *Amphiporus incubator***,** secrets **mucilaginous sheath around herself** after laying eggs on which the newly hatched young feed. Eventually they eat away their mother then wriggle out of the sheath and become free-living predators.

E. Food sharing in insect societies

Food sharing is a feature of the life of **social insects**. It has become a means of communication and maintains the cohesion of the colony and regulates its composition. In honeybees **'queen substance'**, licked from the body of a **queen bee** by workers and circulated through the colony by food exchange between individuals, not only imparts the characteristic colony odour to all but also inhibits the construction of large cells for raising queens. Workers also communicate by sharing food. When a forger returns to the nest, she indicates the direction and distance of a nectar source by 'dancing' on the comb, the type of dance, its orientation and speed carrying the coded information; but she also shares her load with other bees thus recruiting foragers on the basis of the quality and nature of the food.

Food sharing behaviour in ants is ritualized, with much tapping and stroking using the antennae, especially of the donor by the recipient. They exchange food repeatedly so that nutrients and possibly hormones as well quickly become distributed through a colony, which may account for their high level of social organization. In **termites,** which have evolved social life quite independently of ants, bees and wasps, exchange of regurgitated food and saliva determines the composition of the colony at all times. For example, the relative number of soldiers in a termite colony remains unchanged, more being produced to replace any that are removed. As long as some of the workers are in contact with the queen, **pheromones** derived from her faeces and passed into the social stomach inhibit the production of reproductive individuals. **Feeding on faeces** is especially important in **dry wood termites** (belonging to the family Kalotermitidae). Young nymphs, reproductives and soldiers cannot process dry wood for themselves and are fed by older nymphs (there is no worker caste) who periodically produce semi-fluid faeces containing many symbiotic flagellates, instead of the usual hard pellets.

Butterflies of the family Lycaenidae (including blues and coppers) have relationships with ants from **appeasement to predation**, by using ant language. The big green caterpillars of an butterfly *Myrina silenus*, have a raised **dorsal gland** from which **ants lick** secretions. The brown and white caterpillars of *Lachnocnema bibulus*, are carnivorous and feed on certain plant bugs. Ants tend the bugs and eat their honeydew but far from attacking the caterpillars, solicit them for food; the caterpillars respond as other ants would, by regurgitating fluid, which the ants drink from between their mandibles. Other lycaenids have infiltrated ant society even further. The large blue butterfly *Maculinea arion* feeds as a small caterpillars. After its third moult, it wanders around on the ground until encountered by an ant of the genus *Myrmica.* In response to the ant's inspection with its antennae, the caterpillar exudes a secretion from its tenth segment. The ant returns again and again to solicit food until the caterpillar hunches itself up; the ant grasps the swollen fore body in its mandibles and carries the caterpillar into its nest. There the large blue completes its development, feeding on ant larvae. Its ability to provide sweet secretions guarantees its immunity from attack.

Many insects live within ants' nests as a consequence deceit or bribery. about 76 species of rove beetle have been found in association with one species of driver ant in Africa. Some species of rove beetles found in ant nests are fed by their hosts both as adults and larvae and hence are parasitic on the colony but many exploit the situation further by eating the hosts' brood. Rove beetles that live within ant or termite nests are not only tolerated but often gain access to the nest by being carried inside by the hosts. This curious behaviour is stimulated by secretions produced by glands on the beetle's abdomen which is licked by the hosts. In many, the abdomen bears lateral knobs and processes believed to simulate the appendages of the host and is carried arched forward covering the head and thorax.

Slavery is common in certain species of ants **,** *Formica sanguinea* a newly mated queen enters a colony of another ant, *F. fusca,* and collects together and defends a number of their pupae; the resulting workers are loyal to the intruder and kill their own queen. When *F. sanguinea* workers emerge they may raid other nests of *F. fusca* to acquire workers. *F fusca* is thus essential for the formation of *F. sanguinea* colonies but not for their perpetuation.

The relationship between **aphids and ants** differs from those so far described in that benefits are clearly reciprocal. **Ants feed** on **energy-rich honeydew** and **aphids are protected** rather than eaten by **attendant ants** and are often moved to the most productive part of a plant. The closeness of the bond varies with different species: a European wood ant, *Formica rufa,* tends over 60 species of aphid but *Lasius fuliginosus* **ants** get associated specially with *Stomaphis quercus* (Aphids). Some species of ants move aphids on to roots in their subterranean nests and care for them and their progeny as for their own brood but *F. rufa* kills aphids that stray or stop producing honeydew. Many species of aphids found in ants' underground nests are never found unattended and they only defaecate when stimulated by an ant. The relationship is adaptive rather than casual and opportunist .

F. Brood parasites and robbers

A **cuckoo** nestling has a reflex response to contact with anything else in the nest; it nudges it and throws it out of the nest. Having disposed of eggs and other nestlings, the cuckoo gets all the food its foster parents bring and even though it is an abnormally large nestling their stereotyped response to its persistent gape is to feed it and feed it and feed it. The **honey guides** of Africa and Asia also lay in other birds' nests, usually **barbets** and **woodpeckers** to which they are related. The beaks of newly hatched honey guides bear sharp mandibular hooks with which they attack and eventually kill their host's young. Other brood parasites share the nest with their host's brood but escape detection because they resemble them. The mouths and throats of nestlings of at least one species of **Mrican waxbill** are brightly patterned; they are parasitized by *Whydahs* whose nestlings have gape patterns exactly like those of the host's. **Cowbirds** are also brood parasites but in Panama have a reciprocal relationship with some oropendulas since nestling cowbirds remove and eat botflies from their nest-mates.

Brood parasitism is an extreme form of food theft. A milder form, known as **klepto-parasitism**, is widespread, filter feeders being especially susceptible. The copepod crustacean, *Ascidiola rosea,* lives in the oesophagus of **sea-squirts** and feeds by extracting food particles from the string of mucus passed down from the pharynx. The copepod is continuously -moved along with the food string and has to climb upwards at intervals to maintain its position. Tiny pea crabs *Pinnotheres* live within the mantle cavity of bivalves and pick food-laden mucus strings from the gills. **Gulls** of many species blatantly rob other birds of their food. The feeding flocks of **lapwings** are attended by **black headed** and common **gulls.** The gulls adopt vantage points evenly dispersed through the lapwing flock there usually being several lapwings to each gull. When a lapwing extracts a worm from the soil it is chased by a gull and either lapwing either drops the food or takes flight. The gull chases it in the air and harasses it until the food is dropped when it either catches it or finds it on the ground.

PATTERNS OF PARENTAL CARE

A unique social relationship in the animal kingdom is that between parents and off springs. No matter how non- social an animal may be, at least twice in life it has to socially inter act with conspecifics – mating and parental care .It is efined as - form of parental behavior that appears likely to increase the fitness of a offspring . And the Parental Investment (PI) is a form of parental behavior that increases an individual offspring's fitness at the cost of the parent's ability to invest in future offspring (Trivers, 1972). Parental care takes place:

Most species that provide little to no care are insects, reptiles, and fish that produce many young .In stable environments when both parents have an equal probability of associating with their offspring then both mother and father provide care; in predictably fluctuating environments when one sex has a higher probability of associating with the young than the other, then that sex provides more care; in fish, this is typically males who defend a nesting territory; in birds, this is typically females except under unusual conditions where females abandon their broods in the care of the fathers and start new broods with additional mates; in mammals, lactation predisposes females to care the most.

(i) Starts before the baby is conceived in the form of gamete production. Eggs are large and rich in nourishment.

(ii) Birds provide warmth (incubation) to the egg for the chick to develop and hatch properly.

(iii)The construction of nest takes much time and energy of both parents. A pig walks 5-10 kms to look for a safe place to construct a nest and it takes about 10 hours to construct it (Jensen 1993).

Types of parental care:

1. Neither parent is involved in care of young : Promiscuity is associated with no parental care, the mating system that typifies reptiles . Most solitary insects , 100 teleost fish species with external fertilization, some amphibians and reptiles, birds showing brood parasitism (e.g. cavity-nesting ducks, cuckoos, cowbird), there is no example from mammals under this category.

2. Both parents involved in care of young : Monogamy is associated with bi-parental care No insects, reptiles or amphibians reported in this , a few fish species (e.g. mouth brooding cichlids) , many bird species (e.g. willow ptarmigan; most song-birds; tri-colour blackbirds), and few monogamous species show this trait. (e.g. gibbons, tamarins, marmosets)

3. Mostly Females are involved in care of young : Wasps , dung beetle, and social bees provision brood cells and defend/protect their larvae , females of about 14 species of teleost fishes with internal fertilization and 24 with external fertilization show parental care, in alligators and crocodiles its generally the female alone that guards the eggs and babies, bird species in which the male has less investment than the female during brood care are red-winged blackbirds and wrens. This is most widely used in animals kingdom. Why females provide so much care ? **According to the investment hypothesis : The f**emale invests so much energy, it would be risk for her to abandon her offspring without providing care, since offspring may not survive. **The paternity uncertainty hypothesis says because f**emale is more likely to be parent of offspring than male - male not really gaining from parental care if offspring not his. Lastly there is **association hypothesis,** according to this , the females are more likely to be the parent around during egg laying or birth many a times, due to **internal fertilization** – this situation allows males to leave , females have to care for her eggs . Males physically get separated from progeny. Polygamous mammal species in which only females feed and look after offspring without the help of a male are marsupials, rodents ,ungulates, felids, some solitary primates e.g. orangutan.

4. Mostly Male are involved in care of young : The examples are few in this category , male **water bug** carries fertilized eggs , in fishes the male usually cares for offspring. Parental care occurs in 28% of fish families and among 61% of these the male takes care of the offspring . In about 63 species of teleost fishes , mostly males defend a nesting territory eg **three spined stickle backs**, in **pipe-fish** and **sea horse** female places fertilized eggs in male's pouch, birds living in flooded marshes e.g. jacana , tinamous and moorhens or migratory birds e.g. sandpipers and phalaropes and ground nesting ostrich , however, very few mammals belong to this category . Males of Golden lion tamarin of Brazil are worlds finest fathers. The female generally gives birth to twins, her job is only to feed babies, the rest is done by father alone. He carries them on his back day and night , protects them from heat, rain and predators.

5. Relatives are involved in care of young / alloparenting : Eusocial insects where sisters (full and partial) care for eggs laid by their mother (e.g. bees, termites), no fish, amphibians or reptiles reported, among birds **helpers-at-the-nest are found in** eg **Florida Scrub Jay, green wood hoopoes, white-fronted bee-eaters, babblers, and Mexican Scrub Jay .** In **elephants, wolves, dwarf mongoose, monkeys, lions** the related females , called **aunts** help in feeding the baby , related elephants help each other in acts like while mother drinks at a water hole, the aunt guards the young white-footed deer mouse, prairie dogs, banded mongoose, spotted hyena show communal denning, related females help making a den and can also look after the babies in the den , thief or sneaked suckling is reported in elephant seals .

10. 4 Communication in animals vocal, tactile, visual and chemical

chirping of crickets, roaring of tigers, singing of birds, monkey calls, barking of dogs, distinctive smell of urine of cats and dogs, coloured feathers of birds and beautiful wings and fins of butterflies and fish are used by animals for communication. Communication has been defined as :

(i) Biological communication is defined as action on the part ofone organism that alters pattern of behaviour in another organism.

(ii) Communication is a fundamental property of all social systems. It occurs at several levels between individuals, among members of groups and societies and among societies that live in the adjoining territories.

(iii) Communication - according to Scheflen (1964) -communication includes all behaviours by which a group forms, sustains, mediates, corrects and integrates its relationship."

(iv) Communication is transfer of information from one individual (producer or signaller) to another (receiver) that influences the listener's behaviour.

(v) Communication involves an action on the part of one animal that alters the behaviour of another (Wilson 1975). After receiving the signal, the second animal modifies its own behaviour accordingly.

(vi) Communication is mutually beneficial transfer of information between signaller and the receiver when they have the same interests.

(vii) Communication occurs when signals are given out by one animal which are used by another to predict the behaviour either of the first animal or of something else in their environment, after perceiving the signal, the second animal modifies its own behaviour accordingly.

The essence of communication is the relationship between **signaller** and **receiver;** a bird gives an alarm call towards an approaching cat, and all the other birds fly away, the bird that had spotted the cat passed on the information to the other birds.

Animals use communication to attract mates, ward off predators, mark territory, and to identify conspecifics. Communication helps animals survive, therefore, it is adaptive.

The advantages of communications are:

1. It helps in recognition of species, individuals, neighbours, castes (social insects), kin, and demes .
2 .It facilitates courtship and mating between males and females of same species through acceptance or rejection.
3. It prevents agonistic interactions and promotes the establishment of social status between conspecifics.
4. It facilitates social animals to herd at dusk or at the time of danger.
5. It accelerates coordination among hunting animals.
6. It plays crucial role during parental care.
7. It alerts kins in a social group through alarm calls

Types of communication

Auditory Communication

Sound is the most used form of communication in animals. Proper vocalization in vertebrates and noises made by invertebrates using special structures are included in this category.

Crickets, birds, amphibians, bats, whales, primates all have extensive use of

sound (Acoustics) .The **deer** give **alarm calls** for approaching tiger; male frogs call to attract females; bats use **echolocation** as a form of communication as well as for hunting . Bird song serve both territorial and courtship functions.

Other animals use sounds to communicate danger, reproductive readiness, and species recognition.

Animals make different sounds to communicate. From the spine chilling roar of a lion to well composed whale songs to chirpy songs of birds. Sounds are waves of alternating pressure changes that pass through a medium; air, water or solid .The intensity or volume of sound is measured in decibels (dB).

Visual Communication

Light signals detected by the eyes come into this category- like gestures, postures, and facial expressions, courtship and aggressive displays in many birds, fish, amphibians and mammals ,raising of hair and colour change are some of the good examples of visual communication.

There are two types of visual communication**.**

(i) Badges - includes the colour and shape of the animal. This involves ,orphology.They are **structural adaptations.**

(ii)Displays- These are the things or acts animals do to communicate. They are **behavioral adaptations.**

Visual communication is most used during agnostic behaviour and in courtship. **Wolves and dogs** use visual behaviours such as lowering their tails and lying on their backs to show submission. To show dominance they stare at each other, raise their fur, and bare their teeth. Male **stickleback fish change colours dramatically during breeding season.**

Understanding vision and visual systems involves an understanding of the properties of light. While humans can see light from **sun** in a visible spectrum, many animals can see **infrared** and **ultraviolet** light invisible to human. Some animals have exceptional **colour vision**, others have poor colour vision. Some have exquisite **night vision**, others have poor night vision.

Visual communication is the most important to monkeys and apes and certainly the best descried and understood. Primate eyes have exceptionally good capability of perceiving very small movements small differences in shapes.

Visual signals in non human primates include

(i) Postures

(ii) Gestures including facial expressions

(iii) Movement of tail

(iv) Pile - erection

Chemical Signals

Communication through chemicals falls in this category. Substances that can be picked up by the sense of taste or smell are **pheromones** . They are produced by special ducted glands and are proteinaceous in nature. Found widely in insects and mammals .

Chemical signals are the primitive form of communication among animals This form of communication has been well studied and documented. Chemical signals sent and received by individuals of the same species are called pheromones. Pheromones are powerful, a few pheromone molecules released into the air or water through urine, sweat, or other bodily secretions are enough to influence another animal's behaviour. Unlike visual, sound, or tactile signals, pheromones can persist in the environment for a long time. This is important for many cat species, for instance, because females release pheromones signalling fertility without knowing when the males will receive them. Because of their long duration, scent has the great advantage that it can be left to transmit information while the animal that made the signal goes away and does something else. It is, however, a relatively slow form of communication.

Tactile Communication

Communication resulting from actual physical contact are through tactile signals. They are used extensively in social bonding, infant care, grooming, and mating.The type of signal most frequently used by a particular species is directly correlated to the sensitivity of their receptors. Hence an animal with keen eye sight will use visual signals, whereas, one with poor eye sight, but a keen sense of hearing will use acoustic signals. Tactile Communication is when animals use touch in one or the other ways to communicate something to each other. In our day-to-day life we see a cat rubbing its body against ours or our pet dog offers us its paw this way they are communicating their affection towards us.

Parental care in animals:

The word parental care is generally used for higher animals, for lower animals more appropriate term is brood care. Social insects show some degree of brood care, specially members of phylum arthropoda, that too by insects. It is worth noting that arthropods care about their babies in many ways: (i) they can lay eggs near future food of larvae (ii) they can lay eggs inside the future food of larvae (iii) they can carry them on their own body (iv) they can construct special chambers or nests for their larvae. Nests are important as they keep eggs and hatchlings warm and provide protection from predators and the elements. They are a safe, warm place where the female lays eggs and she or her mate can protect them. Animals spend days or weeks building a nest, while others simply scrape a small depression in the soil, or pile a few twigs together. Others lay their eggs in the nests of others or take over abandoned nests. In birds different nest structures include: Domed, suspended, cup, hole, cavity, burrow, mud, saliva and debris. These nests can be found in rocks or buildings, ledges, in water or nearby, open ground, growing herbage, under trees or shrubs, in a crevice or hole in the tree or on a branch.

The nests formed by animals specially insects , fishes and birds are so varied that a full length separate chapter can be written on their different forms and structures. **Dystrophaptic** insects lay their eggs near the larval food, **eutrophaptic** insects like butterflies near leaves on which their larvae feed, some supply eggs with protective covering, some remain with eggs and larvae, some build nests and put their larvae inside with food, species such as leaf rolling weevils *Byctiscus betulae* make cigar shaped nests **by rolling the leaves, some hydrophylidae** build small floats in which the eggs are embedded to float, *Ichneumon* flies use a sting to drill a hole in a living host and then deposits the eggs, sand wasps make an under ground nets, then catch the food, put it in the nest, lays eggs and seals the nest for protection, spiders regurgitate food, cockroaches feed their young, whip scorpion females carry their young, Male water bug carries fertilized eggs on his back. Many beetles excavate chambers underground to store and protect the resource and the larvae developing within it from predators and desiccation. This intensive processing requires the collaboration of both parents . Rotting wood presents a unique resource. A number of insect species show parental sharing in brood care. *Cryptocercus* roaches pair for life. The adults chew a series of galleries interspersed with large rearing chambers in rotting logs. Young nymphs require the transmission of intestinal flagellates through proctodeal trophallaxis from their parents. Nymphal growth is slow , and the nymphs' diet is supplemented in the early stages with parental hindgut fluids and fecal pellets salid beetles are also monogamous, and cooperate in construction and defense of interconnected galleries in rotting wood. Larvae of different species have differing abilities to chew and process wood for food; however, all depend on their parents to some extent in this endeavor. Colonies generally have overlapping generations and cooperative brood care. Colonizing adults share galleries with offspring in all stages of development, and with first generation non reproductive adults. In some cases, young adults assist parents in the construction and repair of sibling pupal cases and other tasks.

Cooperation in excavation of brood galleries and rearing young is also known in the *Minarthrum* bark beetles , and other scolytids . Complex cooperation between the sexes, with division of labour, occurs in many species of scarabaeine dung beetles. Females in the genus *Copris* and many *Ontophagus* species dig tunnels and brood chambers under dung, pushing dirt up to males higher in the tunnel, who in turn push it out. When excavation is complete, males transfer dung from the surface to the female in the tunnel and she constructs the brood ball. Typically the male remains with the female for most of this process, but disappears from the nest soon after eggs are laid in the dung (Halffter and Edmonds 1982). Some *Cephalodesmius* dung beetles pair bond for life and cooperate extensively while rearing larvae (Monteith and Storey 1981). The female excavates the brood chamber while the male stands guard at the entrance. The male then forages for detritus (leaves, flowers, and fruits), which he passes to the female. She adds faeces and shapes the material into a ball, which is allowed to ferment for a week. The female then divides the ball into smaller sections for each larva. For several weeks, while the larvae are growing, the male continues to provision the nest. When the young approach pupation, both parents seal themselves inside the chamber with the larvae.

Parental care occurs in 28% of fish families and among 61% of these the male takes care of the offspring. In fish the fertilization is usually external. This means the males and females have the same costs of deserting a clutch of eggs.

Most species have no parental care once the eggs are fertilized. Whatever little parental care if there, is provided by the males. Parental care in fish includes: making a nest, burying eggs, chasing predators, oxygenating, cleaning, carrying eggs , and oral brooding **(yellow head jaw fish**) actually guards the eggs by holding them in his mouth.

Males are territorial, females mate with males on the male's territory, fertilization is external, the eggs are deposited on the substrate, and females leave. Males then tend to have a closer association to the nest . Site for nests could be hard substrate, weeds, algae, and shells. Fish have come up with three modes of reproduction depending on the method they care for their eggs:

Oviparity-- Lay undeveloped eggs, 90% of bony fish have external fertilization, so they come in this category, cat sharks, ground sharks carpet sharks and nurse sharks though have internal fertilization but are oviparous **.** In fishes, oviparity is most common; the eggs are inexpensive to produce, and as eggs are in the water, they do not dry out (oxygen, nutrients are not scarce). The adult can produce many offspring. The survival of individual eggs is very low, so millions of eggs must be produced in order for the parent to successfully produce offspring.

The other modes have their advantages, the eggs are much less prone to predation when carried within the mother, and the young are born fully advanced and ready to deal with the environment as miniature adults. The adult must supply nutrients to its offspring and can only produce a few eggs at a time.

Ovoviviparity- This can have two types one where the egg hatches inside the body of the female there is little internal development without direct maternal nourishment and babies are born advanced at birth (**most sharks + rays**).Very rarely a larva or less developed baby is born , a mother helps it feeding members of family **scorpeaniforms produced such babies e.g. rockfish**

Viviparity- Internal development- direct nourishment from mother-Fully advanced at birth **(hammer headed sharks and surf perches) .**

Many fish species build nest in one form or another, whether it is a simple **pit** dug into the gravel or the elaborate **bubble** nest. No special breeding set-up is needed, when ready to spawn the fish construct a nest by blowing bubbles, often using vegetation to anchor the nest. During the mating season, bowfin males prepare a saucer shaped nest, then male invites a female to spawn, after fertilization male guards the eggs and hatchlings. The male keeps the nest intact and keeps a close eye on the eggs. The Gouramis, Anabantids and some catfish are the most common nest builders. Some lay eggs on a flat surface, like a stone or plant leaf or even individually placed among fine leaved plants like Java moss. The parents usually form pairs and guard the eggs .The **Cichlids** are the best known species for this. Some **Catfish and Rainbow fish** are egg attenders.

In mouth breeders the females usually lay their eggs on a flat surface where they are then fertilized by the male. After fertilization the male picks up the eggs and incubates them in his mouth. Even after hatching the fry will return to the safety of their mothers mouth if danger is near. Brood numbers are usually small, since by the time the fry are released they are well formed. The well known mouthbreeders are the **African lake Cichlids.** The other mouth breeders are catfish, anabantids, killifish. Fish with internal fertilization do not lay eggs at all, they are fertilized internally and grow inside the mothers body. The broods are small and the fry are well developed when born. The **Guppy swordtail** and **Platy** are the best known members of this group.

In **amphibians** most common form of parental care is in the form of **guarding of eggs** by one or both parents. **Salamanders** and **caecilians** protect their eggs, sticky caecilian female of Sri Lanka makes a cluster of her eggs and then she protects them by coiling around them until they hatch 10 % of **anurans** exhibit parental care, mostly in the form of egg attendance by males, some attend offsprings also, in some *Dendrobates*, some **hylids** females attend tadpoles and provide them unfertilized eggs to eat for nourishment. *Pyxicephalus* and *Leptodactylus* frogs look after their tadpoles. Many species carry eggs on their backs e.g. **midwife toad, gasthrotheca**, *Hemiphractus*, **and** *Felctonotus*. *Rhinoderma darwini* males carry eggs in vocal pouches. *Rheobatrachus* are gastric brooding frogs.

The young of most egg-laying reptiles hatch long after the parents have abandoned the eggs; a few lizards and snakes guard them, and pythons incubate their eggs for a while. The young of those female snakes that carry their eggs inside the body until they hatch also receive no parental care. Among reptiles only crocodiles and their relatives tend both eggs and hatchlings. In contrast, nearly all birds provide extended care for their offspring. The exceptions are brood parasites, which foist their responsibility onto other species, and some megapodes, turkey-like birds of the southwest Pacific. Females swallow fertilized eggs, they develop in stomach and are spitted back through mouth as froglets.In **reptiles** parental care is less common, its almost non existent in turtles, except for that female turtles dig holes to lay eggs, bury them and leave. **Crocodilians** appear to be the most social reptiles, and parental care for young after hatching is probably universal among crocodilians **(Lang, 1987).** All 21 living species build nests and defend an area around nest(Pooley and Gans 1976). Females guard the nests .Young crocodiles call from inside the egg shells when nearing hatching. The female hearing the calls digs the eggs out and carries all young in her mouth and takes them to water. The female **King cobra** makes and guards a nest too. Parental care is shown by Iguanas of Galapagos-the females remain near the eggs and defend the surrounding area. Shifting of young ones from one place to another is seen in many animals.

Nest building is very typical of birds. There is a great variety of nests. Both male and female swallows participate in making a nest , but later it's the mother who looks after the nestlings.

Among birds , some chicks , at hatching, are entirely dependent on their parents, while others are able to leave the nest and begin finding their own food within hours of hatching. Based on such differences, young birds are generally categorized as either altricial or precocial. Because of variation within these two broad categories, ornithologists more precisely classify young birds into six categories **(Gill 1995):**

a. **superprecocial** : young are completely independent at hatching; no parental care e.g. megapodes

b. **precocial** : young leave the nest soon after hatching and follow parents , young can feed themselves almost immediately e.g. waterfowl, shorebirds, and gallinaceous birds

c. **subprecocial :** young leave the nest at hatching and follow parents ,young are fed by parents (or at least shown where food is located by parents) , e.g. rails, grebes, and loons

d. **semiprecocial** : young are somewhat mobile at hatching but remain and are fed by their parents e.g. gulls and terns

e. **semialtricial** : young not mobile at hatching & are fed and brooded by parents , eyes of young open at hatching (semialtricial 1) or within a few days (semialtricial 2, e.g., screech-owls and herons, and hawks.

f**. altricial :** young are naked, blind (eyes closed), and helpless at hatching , e.g. songbirds, woodpeckers, hummingbirds, and pigeons

After hatching, avian parental care may involve **brooding** and **feeding** nestlings as well as **protecting young** from predators. Only a few species (brood parasites and the mound builders or megapodes) exhibit no post-hatching parental care. For those that provide care: bi-parental care is predominant ,female-care only has been described in about 85 species (those with lek polygyny mating systems plus promiscuous species like humming birds) ,male-care only has been described in about 30 species (polyandrous species) .

The food given to young birds contains all the moisture they need, and parents do not bring them **water to drink** (Skutch 1976). Notable exceptions are the sand grouse (e.g., the Black-bellied Sand grouse to the right) --- parents (particularly males) have specially modified abdominal feathers with great water holding capacity. In fact, these feathers have structural modifications (the barbules are not hooked together) that make them three to four times more absorbent than synthetic sponges (del Hoyo 1987). Adults may travel great distances to soak up the water in the abdominal feathers, then fly back to the nest so their young can drink the water from their plumage (Skutch 1976).

Predators of various types prey on nestlings, and adults in most species exhibit some form of defence when potential predators approach a nest. Defence may involve calling, approaching the predator, or, in some cases, even striking the potential predator. **Pheasants, hens, and ducks** do not feed young, instead, they give parental care in a different way. They guide them to food, chase the predators away . **Song birds** and flycatchers carry flies, caterpillars and earthworms for babies, Female **earwigs** keep a close look at eggs, if they start drying she carries them individually to a damper place. The **giant penguins** of Antarctica take particular care to protect eggs from and young from snow and cold by keeping them warm in a special abdominal fold.

In most birds the bond is established through **imprinting** during a limited **ontogenetic phase (sensitive period).** There are two types of young **altritial and precocial .**Some birds , rodents and mammals have altritial young. These babies are born helpless, nude, deaf and blind, do not move , whereas, babies of precocial babies move soon after they are born, they can see and hear, social interactions begin very early. Altricial young are typical among **carnivores**, the helpless cubs stay back in den, while parents go hunting. A young active baby born to meat eating animals would have hampered the hunting. On the contrary This baby would fall an easy prey. As against this species of ungulates are precocial, it helps them run away from predators , soon after they are born. A general rule is that species with one or two young **(oligotocous)** e.g. cattle and primates are precocial and species with larger litter size **(polytocous)** e.g. pigs .

Food supply or **provisioning** forms the largest part of parental care. Many birds feed their young specially insectivorous and carnivorous birds, the food is caught by parent and brought to the young, the babies **beg** for food either through vocalization or by tapping, nudging. it is either fed directly into the beak of nestling or is torn into small pieces(Hamer and Hill 1994) . Among altricial (and semi- and sub precocial) species of birds, one or both adults begin to feed young (or show young where food can be obtained) soon after hatching. Birds carry food from long distances , from sea, lake of forest. This food is provided to the young in partly digested condition , parents eat the food, store it in the stomach, it is partly digested. It has been well documented in Sea gulls by Tinbergen (1950). As the parent arrives , a slight jerk on nest acts as a stimulus for fledglings to open their mouths , the sight of that stimulates regurgitation in parents. In most socially monogamous species plus some polygynous species, both sexes help provision the young. Among birds that deliver food to young, food may be transferred from adult to young in several different ways (Pettingill 1985):

- food is carried in the bill and placed in the open mouths of the young **(most passerines)**
- food is swallowed by adults and later delivered to the young by:
    - regurgitating the food into the mouth or throat of the young (e.g., **waxwings, hummingbirds, and herons)**
    - regurgitating the food into the nest or somewhere nearby where young can pick it up (e.g**., gulls)**
    - opening the mouth and letting young reach in and retrieve the food (e.g., **pelicans and cormorants)**
- food consists of 'milk' (produced in the crop) that is regurgitated into the mouths of the young (e.g., **pigeons and doves**)
- food is carried in the talons to the nest and then either torn into smaller pieces and fed to the young (e.g., raptors with young nestlings) or given to the young whole (e.g., **raptors with older nestlings)**

After feeding nestlings, adults often pick up fecal sacs (packages of excrement surrounded by a gelatinous membrane that may be eaten (particularly when nestlings are very young) or carried from the nest for disposal.

Among mammals the parent- infant communication begins through chemicals, followed by hearing and sight (Romeyer 1993). Licking plays an important role (Alexander 1986), it cleans the baby and through saliva scent marks the baby. Mother gets the ready nourishment and hormones from foetal fluids. All marsupials are unique for having a pouch to keep the baby. In kangaroos the offsprings stay close to mother until they are sexually mature- from 18 months to 3 years old gets inside the mothers pouch. Among ungulates **hider species** (pigs, cattle) are those where the young remains at or near the birth site for some time after parturition. In **follower species** (deer, antelope) offsprings start moving around with mother.Under both circumstance the mother has to form a strong bond to motivate to leave the grazing areas and return to baby. Shifting of babies to a safer place is a common sight in most mammals specially rodents cats and dogs . They use teeth to get the hold over the lose skin of baby , pick up and take it to a safe place.

All mammals provide milk to their babies produced by mammary glands. Many **carnivores** show regurgitation in wolves, dogs, its common to feed like this to 3-4 week old pups (Malm 1995). **Female wild boar** forms a mound of branches, plants, leaves to protect the nest and young ones inside. Female of **garden dormice** doesn't want to lose her babies going from one place to another she orders her babies to hold on to her tail, the babies literally climb on their mother. King fisher makes an unlined nest , when the eggs hatch both parents bring food to feed them through the process of regurgitation.

In **non-human primates** the parental care is important and extensive, the early development of social behaviour occurs during interaction with the mother. As the infant matures it interacts to a considerable extent with its peers, but these interactions are largely controlled by the mother. These include rooting, grasping, clinging, finding the nipple, gesturing, vocalizations and other social signs. **Monkeys** spend most of their early months, and apes most of their early years, clinging to their mothers in a ventro-ventral position or riding on their backs, and when moving about most mother give little if any support to their infants. It is thus essential for the infant to be able to cling to his mother as she runs or leaps about. The infant's ability to cling depends on basic reflex patterns. This response is still present in the human baby as the **MORO reflex**, given on stimulation of the vestibular organs or the muscles of the neck. In addition to clinging with hands and feet, an infant monkey also holds on to its mother's nipple with its mouth. The nipple thus provides an additional point of support in baby **gorillas (Fossey 1975)** . Sucking has a soothing effect on the baby, even though it obtains no milk thereby and even if it has never previously been fed from breast or bottle. Riding on the dorsal side of mother is seen in some cats also.

Golden Lion tamarins are small-bodied new world primates (family Callitrichidae; tamarins and marmosets) that show a great deal of parental care by both sexes (true of all tamarins and marmosets). In many mammals, usually the female is takes care. But specially in marmosets and tamarins even the males indulge in infant care .Why do males help? **(**i). Tamarins are arboreal and very mobile during the day. They have territories (40-200 ha depending on the species) that they actively defend by traveling and patrolling. One of the principle forms of parental investment is infant carrying. Although the body size in lion tamarins is small, females generally produce large twins relative to their own weight. Females are about 600 g and give birth to infants that are 60 g .Therefore they need help in caring for the young.(ii) The reproductive female carries offspring on her back the first several days, nursing them every two hours or so. After approximately a week the male starts carrying the offspring .

Harlow (Harlow and Suomi, 1959) provided rhesus monkey infants with two surrogate mothers one consisting of a hard wire framework with a nipple providing milk and another with soft cosy body and no nipple and milk. When rhesus monkey infants were given these artificial , they spent nearly all their time on the soft, cosy mother even though they could obtain no milk from her . The rhesus babies jumped to the wired mother to drink milk and quickly returned to soft mother.Textural stimuli are important in determining an infant's clinging preferences.

How do parents ensure that their own offspring receive their parental care? Can animals recognize their own offspring? **Mexican free-tailed bats** live in cave colonies that can contain millions of individuals. Females give birth to a single offspring which they leave in the cave when they go to forage. The female returns to the spot where she last nursed the pup but is **besieged** by babies next to her own offspring. Given that there were so many pups so closely packed it was thought that feeding must be indiscriminate. Blood samples of mothers and nursing pups demonstrated that females nurse their own pups at least 80% of the time. They probably do this by a combination of smell and sound.

Two **swallows** that nest in burrows in clay banks are the **bank swallow (colonial nester**) and the **rough-winged swallow (solitary nester).** Bank swallow young have diverse vocalizations and parents rarely make a mistake despite the high densities in which they are found. Rough-winged swallows however, will readily accept the offspring of distantly related individuals and will even foster the offspring of bank swallows.

Siblicide / infanticide :

In some birds it is common for **siblings (brothers and sisters)** to compete for food and space vigorously and even **kill each other** e.g. blue footed booby and black eagle siblings kill a weaker sibling. The parents are generally indifferent to this behaviour. This might be explained, not just as the result of the offsprings **selfish genetic** tendencies, but also as part of a **parental strategy** to identify the **best offspring** and to concentrate resources where they will do most benefit. Various species of **pelicans, eagles and magpies show** .Siblings have an interest in small broods because that way each sibling gets a greater share of food, more space in the nest. If a mother has a choice of saving lives of two of her offsprings of different ages. The one she neglects is bound to die, in this case she would save the older and let the younger die because according to Dawkins (1976) she has invested higher proportions of her life's investments in the older baby.

It has been observed that bird parents kill their weak baby in the nest, a phenomenon now widely observed in other animal species also called **infanticide.** Infanticide, is associated with the killing of offspring after birth. This, too, is found in many mammalian species. **Syrian hamsters**, for example, may **cannibalise** their young when the external circumstances become too unfavourable. **Male cats of all kinds** (including the domestic cat) may kill a female's offspring to make her stop nursing and return to fertility, so that they can fertilize her themselves. **Mice, horses and zebras** and many **primates** such as **langurs, baboons** and even our closest, the **chimpanzee,** all engage in infanticide. In all cases, infanticide can be regarded as part of a male reproductive strategy – albeit an unconscious one.

There are two more unusual behaviours worth mentioning , one **nest parasitism** and other **maltreatment** . Cuckoo parents do not perform real brood care, their females deposit eggs into a suitable nest belonging to another species. Young cuckoos hatch earlier than the offsprings of , they throw the hosts young out of the nest, and keep eating from the host adults. This phenomenon is called **nest parasitism**. **Maltreatment** by mother and aunt have been reported in various animals. The babies can be pulled, pushed, slapped, carried clumsily . Among langurs and rhesus inexperienced mothers have been seen sitting over their babies ignoring their distress cries. Harlow named this **" deprivation syndrome"** due to the absence of proper parental care.

Unit - 11

Learning and memory

Structure of the Unit

11.0 Objective

After reading this unit you will understand the most interesting part of animal behaviour that is how do animals learn? First I shall teach you the difference between learning and instinct. You will know how scientists observed that smallest creatures like earth work also learns. Animals learn by using different methods or types viz Habituation, Trial and error, conditioning , cognition and lastly through Imprinting. Learning and memory are two sides of a coin. There are two types of memory Short and long term . You shall learn to distinguish them . At last in this part, you will understand how things are learnt and memorized in brain what neural mechanism is responsible.

The last part of this unit will deal with domestic, pet and zoo animals. What are the advantages and disadvantages to the animals .

11.1 Introduction

A number of surprising findings have lead many researchers to believe that virtually everything we encounter is learned and is stored away in the brain. Although we may have entered the minutest things of our lives into our minds computer, we are not able to consciously recall much of it. Sometimes, we can't even recall what we have tried to memorize, but apparently the information is there, the fault lies with our recall techniques. If our research ever enables us to recall earlier events so vividly, we might reread novels – without holding it are hands and all our exams would be virtually open book tests. The world is full of amazing feats of learning ability in human beings.

Case of photographic memory: The proof of such memory has been demonstrated with stereo grams these are apparently random dot patterns on two different cards that, when superimposed or put together by use of a stereoscope, produce a three dimensional image. In one such experiment, a woman was asked to look at a ten thousands dot pattern for one minute. After 10 seconds, she viewed the other dot pattern. She then recalled the position of the dots on the first card superimposed it with the present card and could see the image of alphabet "T" such persons are called – **Eidetikers or Mnemonists.**

Some people are able to photograph mentally a picture or a page of text and remember every detail. If a normal person looks at a painting and then looks away at a blank wall, he will be able to describe the picture in general terms. But the individual with eidetic or mnemonic or photographic memory can actually project the entire image on to the wall and describe every detail in the picture perfectly. Classical animal learning studies have been dominated by the works of Watson, Hess Lorenz, Harlow, Niko Tinbergen Skinner, Pavlov and Thorpe. Learning occurs in a great number of different animals under a wide variety of circumstances. All animals learn from ants to elephants and from protozoa to primates.

Animals that live under human care in defined area, prevented with fence and cages are designated as " in captivity" . Captivity can be used as a generalizing term to describe the keeping of either domesticated animals (livestock and pets) or wild animals in zoo. This may include for example farms, private homes and zoos. There are three types of captive animals : Domestic, Pet and Wild (in zoo).

11.2 Learning

Learning has been defined by many different ways, they all mean almost same, some are given below:

Learning is a process which manifests itself in an individual's behaviour as a result of experience. Learning ability has its control by genes but learned processes in an individual's lifetime are not genetically transferred.

Learning involves a change in behaviour, often long lasting. It is not passed on to the next generation.

Learning is a general term for all behavioural changes affected by experience. New neural circuits are formed for its execution.

Learning indicates a broad range of behavioural modification due to experience in an animal's lifetime. It brings changes in the brain.

Learning represents change in behaviour, it is different than instinct because it is not genetically controlled and is flexible.

Learning is a relatively permanent modification of behaviour due to motivation. It is associated with reward and punishment However, in the absence of reward or punishment it can go extinct.

Learning is a specific change or modification in behaviour involving the nervous system as a result of experience with an external event or series of events in an individual's life.

11.2.1 Types of learning

Learning has been classified differently by various scientists. Thorpe's (1963) classification is most widely used:

(1) Flexible - Habituation , Conditioning , Trail and Error, cognition

(2) Restricted - Imprinting

Let's start with different types

(i) Habituation (ii) Trial and error (iii) conditioning (iv) cognition

(v) Imprinting.

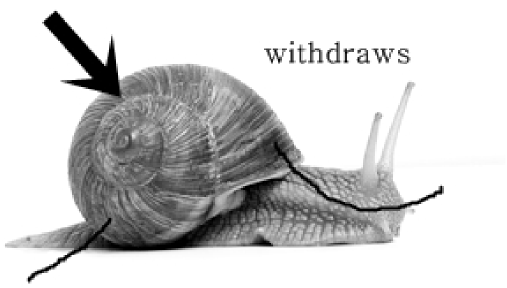
(i)Habituation :It is convenient to deal with habituation first because, in some respects, it is the simplest form of learning. Habituation like phenomena is found in every group of animals from Weevil to Whales. Habituation is important for adjusting an animal's behavior to its environment. By habituation animals learn to conserve energy and time by not responding to an irrelevant stimulus.

"It is the decrease in probability of a response occurring when a stimulus which elicits that response is presented repeatedly or It is the gradual fading of a response when a stimulus that proves to be safe, neutral or irrelevant is given repeatedly".

If a neutral stimulus - that is, a stimulus that has neither noxious nor beneficial consequences, is repeatedly delivered to an organism, it's response to the stimulus tends to decrease gradually and may eventually case all together. By habituation animals learn "What not to do."

For example a Spider is sitting in its web. The experimenter vibrates a point on its web, resembling the signal set up when an insect is trapped. The spider runs out to investigate the source of the vibration, nothing is found and spider returns to its place in the centre of the web. If this same neutral stimulus is given several times, the spider no longer rushes out to investigate; it remains in the centre of the web. It gets habituated to that stimulus.

A snail crawling across a sheet of glass retracts into its shell when the glass is tapped. After a pause it emerges and continues moving. A second tap causes retraction again but it emerges quickly, frequent tapping on glass ultimately cause no response at all in snail and it will keep on moving. This is called habituation.



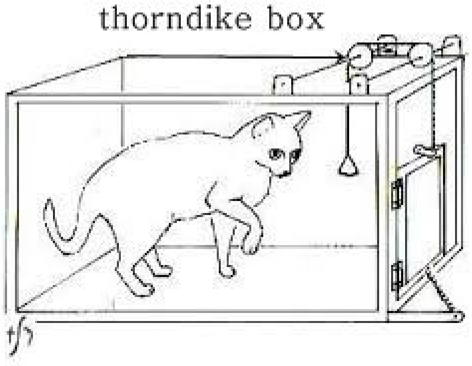
Almost all animals are able to learn not to respond to repeated stimuli which have proved to be harmless. If you make an unusual noise in presence of family dog, it will respond - usually by turning its head and ears towards the source of the sound. If, however, the stimulus is given repeatedly and nothing pleasant or unpleasant happens to the dog, it will finally cease to respond.

Habituation is considered distinct from fatigue . Habituation has been reported to have correlation with a change in Central Nervous System. Whereas, fatigue is the result of accumulation of lactic acid in muscles. A fatigued animal will not respond to a stimulus even if it has been changed, whereas, in habituation the animal responds if the nature of the stimulus is changed. Secondly, after a rest the fatigued animal will be responsive to the same stimulus but a habituated animal shall remain unresponsive to the stimulus even if it is given at 24 hours intervals. Fatigue is a temporary change in body physiology; habituation is a permanent change in Central Nervous System.

(ii)Trial and Error Learning

Learning by trial and error has basic instincts or motivation or drive or urge associated with it. When animals are motivated by thirst, hunger, sex or fear they show restlessness, and exploratory or appetitive behavior - during the course of which it performs spontaneously a variety of motor patterns viz-sniffing, walking and looking around. If one of these patterns is followed by reinforcement e.g. a hungry animal while exploring the surroundings receives food and if this association is repeated the animal learns to perform a pattern regularly to that particular situation.

An example will make it clearly why this type of learning is called trial and error. In this early experiment on learning Thorndike used, a problem box .This puzzle box also called Thorndike box is a cage which can be opened from inside by depressing a lever. A cat is shut in, which tries hard to escape, it moves around restlessly, explores its surroundings, bangs its head and paw here and there to somehow open the box, after sometime, by chance it steps on the lever and the door opens. The second trial is the repetition of first, and the third, but soon the cat concentrates more attention on the lever and eventually it moves swiftly across the box and presses the lever as soon as it is confined.



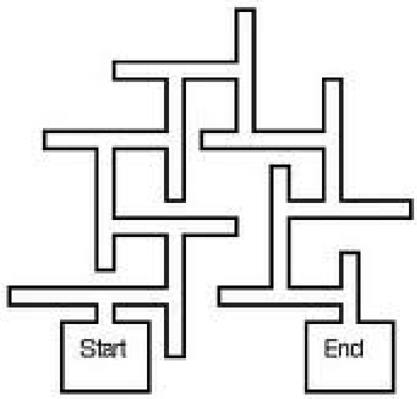
Thorndike’s cats helped him to format a “law of effect” which stated that – behaviour changes because of its consequences. He said that every animal is born into a world which sets the puzzles e.g. A fox learns by trial and error how to enter a poultry farm and escape out of it unharmed after having, a good meal, in the same way as Thorndike’s cat comes out of the box. The cat learns to eliminate behavior which led to no reward and increases the frequency of behavior which is rewarding but the first reward is obtained by pure chance.

John B Watson (1878-1958) is the founder of experiments using a maze. Watson picked rats for his research, and attempted to discover what, and how, (maze is a device with zigzag confusing path where only one correct path leads to the goal i.e.) they learn different things. Watson was fond of watching behaviour of rodents; realizing that they were underground animals, crawling around burrows and sewers, he decided to test their performances in maze. With his works, the maze became a standard research tool for probing the mental processes of animals. Willard small built increasingly elaborate mazes, culminating in a complicated model called Hampton Court Maze. Today we have innumerable number of mazes used by psychologists and Ethologists.

Trial and error learning is by no chance confined to animals with well developed brains. It is shown even by earthworms. An earthworm is placed in the stem of T-shaped tube. If it turns left it is given and electric shock, if it turns right it is returned to its box without punishment. It is claimed by people who have enough patience to complete this experiment that the worm learns by trial and error to associate turning left with punishment and eventually always turns right .

We will consider a modern version of Thorndike's experiment. A pigeon is placed in a sound proof box whose one wall in transparent, enabling the experimenter to watch the bird's behavior. On one wall of the box is a point, which the bird can peck for food a tray comes out with grains. The apparatus has been named after its inventor and is called Skinner box . The pigeon is deprived of food for sometime before it is placed in the box. When the pigeon is in the box, it will start to do all sorts of things. It may turn around thrust its head into a corner, stand still for a moment, coo, and then start grooming its feathers. The pigeon in the box is certain to peck at the point initially just by chance and this produce an immediate effect, the food tray opens and pigeon sees the corn, picks up a grain, and the food tray closes. If each peck is followed by food, the bird will begin pecking at a rather higher rate. The food reinforces pecking behaviour. Once the pigeon has learnt to peck that particular point at a high frequency for food then the apparatus is reset, that the peck no longer releases food, the pigeon continues to peck at a high rate at first, which gradually falls off and ultimately stops completely. This is called extinction. This clarifies, that the animals learn by trial and error to achieve a goal but if they are deprived of reward the learnt process can be forgotten or can extinct.

In another maze learning experiment the hungry rats are left in a Hebb-William Maze. The rats are left to perform in maze, one by one. The maze has two chambers A and B and between them is the maze .



Rat is left in chamber start and Chamber end has food, the rat after overcoming the neophobhia (fear for new surroundings) leave start and comes to maze, the experimenter records number of errors (entering incorrect path) and total time taken in maze. The rat reaches chamber end an gets the food. The rats are given many trials over a period of one month. It is noted that gradually number of errors and time taken in maze reduced . The rats learnt the correct path by trial and eliminating errors and selecting correct actions.

(iii) Conditioning or Conditioned Reflex or Pavlovian conditioning:

The term conditioned reflex is inseparable from the names of Great Russian physiologist I. P. Pavlov (1941) and Sherrington (1942).

A simple reflex and a conditioned reflex are two different things. A simple reflex is the simplest automatic functional unit of the nervous system capable of detecting change and cause a response to that change. Many body activities are controlled reflexly. This term implies an automatic adjustment to maintain homeostasis without conscious effort. Simple reflex are also known as inborn or unconditioned reflexes, whereas, the conditioned reflexes are acquired reflexes.

Pavlov thought that he had discovered a phenomenon which provided the total overall explanation for behaviour. In his opinion, in order to survive, every animal needed two kinds of reflexes one fixed that was inherited also called unconditioned, like the knee jerk closing of eyes the second is acquired, which are learnt, called conditioned, are flexible and steer animals through their changing environments by means of signs, sounds, smells. Pavlov regarded them as the smallest indivisible units of behaviour, as “atom of action” from which could be built up for more complicated repertoires. According to him, all kinds of habits arising from training, education and discipline are due to chain of conditioned reflexes.

Properties of Conditioned of acquired Reflexes:

They are acquired in life. They are not transmitted through genes.

They can be established or abolished.

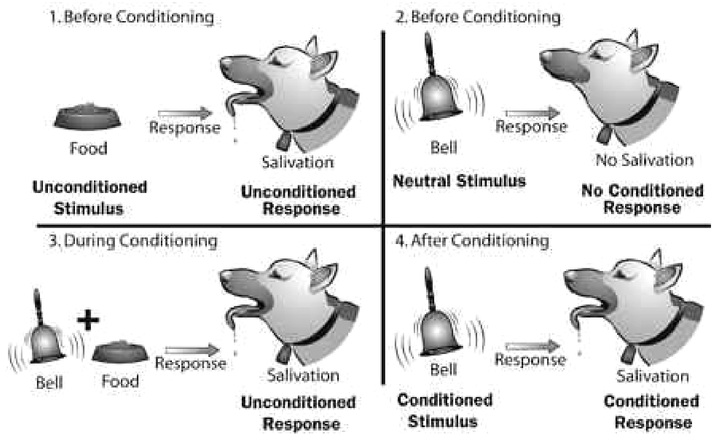
They are always established upon some pre-existing unconditioned reflexes.

Food stimulates salivary secretion. (Even a thought of a sour thing like lemon causes saliva to flow) This is an unconditioned reflex. Now, if a second stimulus like ringing of bell be applied just before giving of food, for some days, the bell sound will be able to elicit salivary reflex, even if no food is given. Such a stimulus is called conditioned stimulus and salivary secretion as conditioned response (CR).

Famous experiment of Pavlov with dogs involved the salivary reflex. Dogs salivate when food is put into their mouths and Pavlov could measure the amount of saliva secreted, by inserting a fistula, through the cheek to the salivary duct, so that drops of saliva fell from a funnel and could be counted. A hungry dog was placed on a stand; dog was given meat powder, which caused secretion of saliva. Pavlov ring a bell just prior to feeding, at first this stimulus caused no response, after repeating the same thing for 5-6 times, saliva began to drip from the fistula soon after the hearing of bell even before the meat powder arrived. Eventually, the saliva was produced after hearing the bell alone. The dog had learnt to respond to a new stimulus which was previously "neutral" and Pavlov called this the conditioned stimulus (CS). The salivation response to CS is the conditioned response (CR). Prior to this learning, only the meat powder or unconditioned stimulus (UCS) was producing salivation or unconditioned response (UCR).

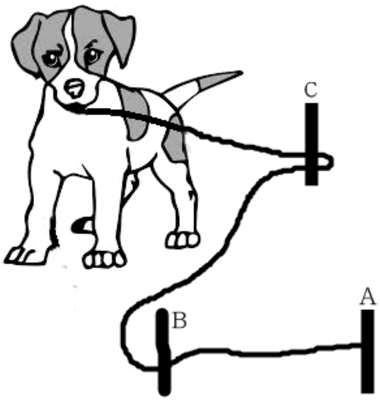
Conditioning in undoubtedly involved with many learning patterns in normal behaviour. Parent ring doves produce crop milk to feed their young ones, reflex of regurgitation of crop milk (UCR) takes place when the chick pecks at breast (UCS) after some time just the site of hungry chick (CS) produces regurgitation (CR) in parents. The stimulus for a particular conditioned learning is more or less specific. If a CR be established with a particular sound then a different sound will be ineffective. If one sound be associated with the "giving of food" and another with "no food" then the animals get conditioned to discriminate between the two sounds.

If a CR be not practiced for several months it undergoes decay due to disuse or if the CS (bell ringing) be repeated several times without UCS (meat) then also the learning goes extinct. The stimulation that follows with a reward is called positive reinforcement and when it is associated with punishment - it is termed as negative reinforcement. Pavlov used positive reinforcement. In another experiment an electric Shock (UCS) causes a dog to lift its paw (UCR), if a bell is rung (CS) just prior to UCS, the dog learns to raise its paw just after hearing the bell (CR). Here the CR is associated with punishment or negative reinforcement.



(iv) Cognition:

Do animals have something like human consciousness? Gallup did classic research that seemed to show apes could recognize their own images in a mirror. The research has been criticized in various ways but has stimulated a lot of follow-up research.



can the dog solve to untangle?
Yes, that would be congnigence

Most animals are intelligent in specialized ways. Rats are good at exploring mazes and handling things with their paws. Pigeons excel at visual discriminations, like most birds. Bees are exceptionally good at mapping the location of pollen sources and conveying this information to other bees in the hive, using the "waggle dance" first identified by Von Frisch. Chimps-our closest relatives among non-human primates-are capable of many forms of complex cognition. Often they perform cognitive tasks in ways that are strikingly similar to humans.

They can be taught to use sign language to label objects, although apparently they cannot learn to generate complex grammatical sentences with any consistency. Chimps also show human-like emotions on occasion, as illustrated by stories of chimp "sympathy" told by researchers like Yerkes and Terrace. Such anecdotes are not usually considered scientific forms of evidence, but some researchers argue that they provide a "gold mine" of ideas for later research or simply for enriching our understanding of animals.

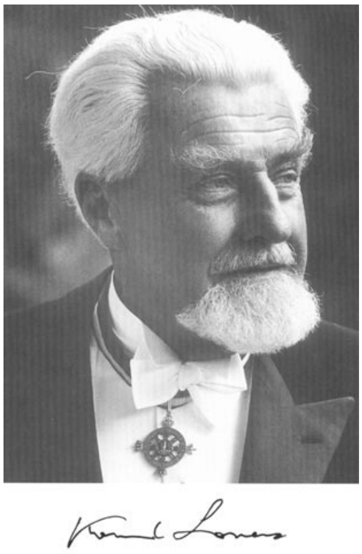
Cognition

Do animals learn simple things only or they have intelligence? Research on animal cognition has picked up in the last 55 years . Cognitive processes such as perception, learning, memory and decision making play an important role in mate choice, foraging and many other behaviours. Today, although there are as many definitions of animal cognition as there are researchers, most scientists agree that animal cognition, like its human analog, basically involves the processing of information: How a subject, within its species-specific perceptual system (auditory, visual, olfactory, gustatory, somato-sensory) receives data from the world it inhabits (including data from other individuals), and, with its species-specific neurobiology, uses its brain to process and act on that information. Behavior of primates has been of special interest. But , large and small mammals, birds, fish, ants, bees, and others have been observed for the search of intelligent behaviour . In the laboratory, animals push levers, pull strings, dig for food, swim in water mazes, avoid electric current, choose colours and patterns . They solve problems to find an escape route, to reach hanging bananas, use a stick to take out termites from hole, use a wooden log to cross water, showing higher mental capabilities like "insight" means the ability to notice and understand a situations, "reasoning" means the ability to combine spontaneously two or more separate experiences to formulate a new activity, which is effective for achieving a desired goal" and "intelligence" means the ability to recognize a problem, formulate a solution and act upon it.

These faculties have been seen in mammals and most in non human primates. They are of course best developed in human beings. Therefore, these terms are part of psychology more than ethology.

(v) Imprinting: (Form of early childhood learning) :

It is a a learning process which occurs at a remarkably early age. **Konrad Lorenz** (1935) was the first one to notice this type of learning and he coined the term "Imprinting". He was a naturalist, lived on his farm with a variety of animals. They had so many pets that his wife used to keep their child into a cage! For his work on imprinting he was given a Nobel Prize in 1973. Konrad Lorenz's observation and interpretations on imprinting are remarkable. He mainly worked with graylag geese and Jackdaws. The easiest way to explain the idea of imprinting is to how Konrad Lorenz's first studied it. On his farm, he found an abandoned clutch of graylag goose eggs. He collected them and put them in an incubator, after hatching the goslings started following Lorenz where ever he went. Then he decided to do a simple experiment. This time he deliberately picked up half of the eggs from a clutch, he left rest for the mother to incubate. When the chicks hatched, he got all of them together under a box, when they were released half of them went to mother and half came to Lorenz. Lorenz called this phenomenon **Praegung**, which is a German word meaning "stamping in" because the goslings were stamped an impression of the particular parent object with which they had their first social experience. Lorenz also noticed that the initial social experience must take place during a critical period early in life.



According to Lorenz imprinting is a unique form of learning because it takes place only during a brief sensitive period early in life. It has great stability, generally lasting for the rest of the animal’s life and Influences the animal’s choice of parents and later a sexual partner.

There are phases of an animal's life when they are likely to be sensitive for some typical learning processes. Many animals and even human beings pass through time periods in their individual growth when certain learning experiences are far more significant than at other times. This means, that, if the individual encounters the same kind of experience outside this period, it will not be influenced as much, and perhaps it will not learn from the experience at all. Such a specific period of time is referred as "critical period" or "sensitive phase". The beginning and end of this period is not sudden but gradual and varies from species to species.

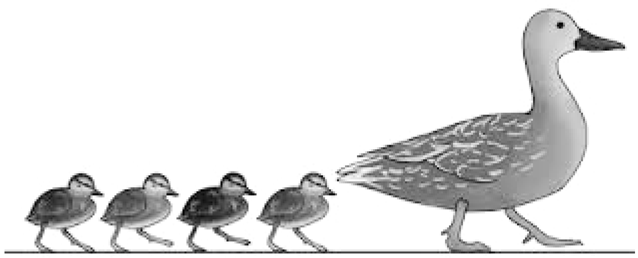
A good deal of work on imprinting has been carried out using birds like - geese, ducks, pheasants, which have precocial young i.e. those that can walk just after hatching. The other kind is altricial. The broad difference is:

A	Precocial	-	start moving soon after hatching / birth e.g. Spiny mouse, hoofed mammals, ducks, mallards, geese
	Nidifugous chick	-	Born with feathers eyes open and move immediately
B	Altricial	-	Do not move immediately e.g. house sparrow, ring dove, pigeon

Nidicolus chick - Born naked, blind and do not move

How are imprinting processes different from other kinds of learning? There are two criteria, both of which Konrad Lorenz described as early as 1935. Most important is the fact that imprinting always occurs within a specific period of time. The existence of such periods lead to second main criterion for imprinting - that experiences made outside of this phase do not have the same influence. Accordingly, knowledge acquired during a sensitive phase cannot be altered at a later stage. This has been called as irreversibility. Earlier it was taken in a very rigid way but now people know there is some flexibility.

Newly hatched ducklings will follow the first moving object they encounter. Usually in nature this is the parent or elder siblings. But in incubator reared birds it is likely to be a man. If the ducklings begin by following a man, they will continue to follow man in preference to adult ducks. Moreover, as the baby birds grow adults they behave as if man belonged to the same species. The birds may even court a man taking him as a mate because that is what they learnt during their early childhood learning i.e. imprinting.



5 years old turkey raised by hand, preferred counting humans, even though there were opposite sex mates of their own species in the same age. But it was further observed that in the absence of human, as a second choice they went to their own species and mated through in a clumsy way as compared to normally reared con specifies.

Some of the mallard ducks raised by parents of another species (surrogated) remained attached to partners of their foster species even after 9 years, although they had been given opportunities to mate with their own kind. Newly hatched birds will also begin to follow inanimate objects such as moving boxes or a variety of other substitute objects (boxes, balloons, toys, ribbons). Buffalo calves, bison have been observed following horses and zebras have been seen following a Car! The strength of following behavior is often increased if the stimulus makes some sort of a noise as it moves. If the newly hatched bird is not given an object to follow in the first days of life, then it may never take to following, will turn out to be a loner and will not accept mates. Therefore, for the development of normal adult social behaviour early childhood learning is necessary.

In an experiment to Eckhard Hess (1964) used mallard ducklings for imprinting studies. The incubators were kept in dark; the young ducklings were kept in dark, in light proof boxes, until the time of the imprinting experiment. The experimental apparatus that was used had a circular runway (as mentioned above also) a mallard duck decoy was suspended. A speaker was fitted too, to make a "quack". The decoy was moved and duckling was allowed to follow for 10 minutes, with the decoy stopping for 20 seconds at regular intervals. Then the duckling was kept back in the dark box until it was tested again the next day. Hess noted that following had started in 1 hour old duckling and continued till 40 hours with a maximum between 13-16 hours. He further noticed that following things made imprinting stronger.

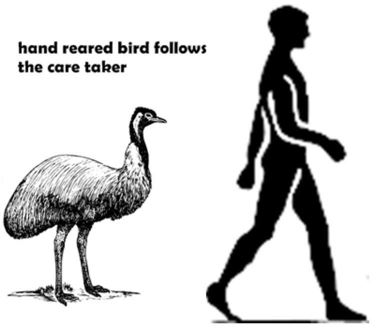
Hurdles in following path then smooth path.

Noisy model then silent model

Raised zigzag climbs then leveled and straight path

Hess called it **"Law of Effort".** In wild all these things and found naturally. When the chicks follow their parents there are fallen wooden logs, stones, ponds that make the following difficult and stronger.

H. F. Harlow has done major and important experiments on mother -infant relationship and effect of isolation on infants. He observed if young monkeys are raised away from their mother, they show serious behavioral disturbances. He denoted this as **"Deprived syndrome"** expressed by general restlessness, aggressive reactions extensive apathy and lack of exploratory behavior. As adults, most of these animals socially abnormal and were become unable to copulate.



11.3. Short and long term memory, neural mechanism of learning

11.3.1 Short term memory (STM) and Long Term Memory (LTM):

11.3.2 Neural mechanism of Learning

11.3.1 Short Term Memory (STM) and long Term Memory:

First of all you must know what is memory? We all are exposed to different situations , by trial and error and other learning methods we solve those situations/problems and subsequently gain experience. Earlier you studied that any change in behaviour due to experience is learning. After this comes a stage called memory - it is the process in which learned information is, stored and retrieved whenever necessary.

STM means very recent memories, usually measured in minutes-to-days. Examples of short term memory include where you parked your car this morning, what you had for lunch yesterday, what dress you wore and remembering details from a book that you read a few days ago.

Once a memory is created, it must be stored (no matter how briefly). There are three steps involved that we store memories: (i) in the sensory stage; (ii) in short-term memory; and ultimately, if needed (iii) in long-term memory. Not all actions we perform need to be stored in our brain .

Sensory storage is very short , after that the learned process is stored in short-term memory. Short-term memory has a fairly limited capacity; it can hold about seven items for no more than 20 or 30 seconds at a time. Important information is gradually transferred from short-term memory into long-term memory. The more the information is repeated (called reverberation), the more likely it is converted to long-term memory and things are stored unlimited amounts of information for a very long time- years.

Short-term memory differs from long-term memory in three fundamental ways (i) short-term memory is lost with time so there is temporal decay where as LTM is almost permanent. (ii) STM has short space to store things whereas, LTM can store vast amounts of information.(iii) STM is stored in the form of electrical current in the neural circuits , whereas, LTM is formed by permanent changes in cell contents/ organelles. Conversion of STM to LTM is called consolidation.

It is believed that short-term memory is a primary function of the prefrontal cortex. Once memory is consolidated, it is carried over to the hippocampus wherein long-term memories are formed and stored permanently accessible for later use.

11.3.2.Neural mechanism of learning

Earlier times people used to wonder in which part of the brain our memories are stored ?Comparative vertebrate brain anatomy gave a clue of where to look in the brain. It was observed that there has been a gradual increase in learning ability from Fish to Man and there has been an increase in the relative size of the cortex . According to this correlation, **cortex** appeared to be the **seat of memory**.

Early classical work by Karl Lashley in early 50s on rats tried to explain involvement of brain and learning. Lashley removed the visual area (occipital) from the back of the cortex and tested the animals for visual learning and retention. He used discrimination situation in the Lashley's apparatus where the animal had to choose the correct one of two doors containing visual stimuli. He used black and white doors - rats **without the visual cortex** could learn to discriminate normally, meaning that visual cortex is not involved in learning visual discrimination. He took another set of rats **intact with visual cortex** and allowed them to learn the test, later he removed the visual cortex, and observed the loss of learned test. The whole experiment indicated that visual cortex was utilized for the retention/storage of learned test related to colour and pattern discrimination.

Lashley found in another experiment that rats were affected in their ability to learn mazes in proportion to the size of the cortical ablation he made in their brains ; the larger the ablation the poorer the ability to learn would be. He also found that it did not matter where the lesion was in the cortex, a lesion of a given size had a given effect whether it was in the visual area in the back side of the brain or in the motor area in the front of the brain. From this finding, Lashley formulated his **"Principle of Equipotentiality"** according to this all parts of the cortex are equal in their contribution to learning and memory or learning occurs at many places of the brain , and that no one part is completely essential for its formation or retention.

On the other hand, another scientist Franz (1952) performed a series of experiments on rats and found that rats retained much information even after both cortical hemispheres were removed; he proposed that learning and memory are not just cortex dependent but have close relation with deeper structures of brain too viz corpus callosum, **limbic system, hippocampus, hypothalamus**, pons etc. He said that once certain tasks are learnt the knowledge or information is passed on to these deeper levels of the brain. When the Hippocampus (an important nucleus in hypothalamus, deeper structure of brain) is removed from brain there is no interference with old memories but new memories were difficult to establish. For example an article is read, understood and discussed, but the moment some time passes, it is forgotten. Hippocampus is an essential part of the brain for converting short term memory into long term memory. When both right and left hippocampuses are destroyed, nothing can be retained in the memory vault. The subject quickly forgets any recently received message.

It is generally agreed that while we memorize things two major changes take place:

I. Change in the connections between neurons.

It consists of following 6 possibilities:

(i) Formation of connections;

(ii) Use and disuse of connections;

(iii) Completion of connections;

(iv) Sensory stimulation;

(v) Destruction of connections;

(vi) Learning and emotions.

(i) Formation of connections: Neurologists favour the hypothesis (it may be noted that most interpretations are based on indirect evidences and assumptions) that learning means establishing connections between neurons. When a blind person learns Braille, connections are made between the tactile area of finger and speech area in brain. When this person feels a certain configuration of dots they bring word to his consciousness. Why we take time in learning? Because it takes time to establish connections between neurons. It explains delayed learning. Another hypothesis is that some neural circuits are already there, learning may be a matter of directing nerve impulse along this pathway. This explains instant learning.

(ii) Use and disuse of connections: It is the property of neural connections that if they are not used they cease to work. Experiments have been done in which one eye of a kitten was kept closed by stitching the eyelids as soon as the kitten was born. That means one eye was prevented from receiving light or to see anything or in other words kitten was prevented to learn anything through that eye. When the stitches were removed three months later - the kitten was virtually blind in that eye. The brain of this kitten was examined. The neural structures of covered eye were abnormal, The neurons were small and their dendrites were also smaller as compared to normal eye.

Connections are fully formed only when they are used. In another situation, fully formed connections can also be atrophied if they are not used. When a rat has learnt to run a particular maze over a period of time, new connection are being formed between neurons. If the same rat is not allowed to run into the maze for a long time-it shows extinction of learned behaviour. It is thought that by use - one connection was formedand by disuse it got degenerated. This explains why we forget our course books?

In human kids sometimes for unknown reasons a child develops a "lazyeye". That is-one of the eyes is not used as it should have been. If attention is not paid to such a child eventually lazy eye becomes blind. But if it is noticed at an early stage and the normal eye is covered and the child is forced to use the lazy eye it promotes formation of healthy, normal neural connections and the lazy eye starts seeing normally.

(iii) Completion of connections: If learning depends on neural fibers making connections between two regions of brain, it cannot occur till these fibers have completed their development and are ready to conduct impulses. One reason why certain things can be learned only at certain times is that the neural structures needed for this learning may not yet have adequately matured.

Why do we learn some things instantaneously and to learn something else we need time and what we call practice or repetition ? Instant learning is possible only when there are pre-existing connections, with proper stimulation they start functioning immediately but whenever time and practice is involved it indicates that connections are being formed gradually. Once these connections are completed the task is also learnt.

(iv) Sensory stimulation: The first step in learning is the sensory input. There must be stimulation from environment, something has to be experienced, seen, smelt or felt. The invention of the technique of sensory deprivation has made it clear to us how important the usual environmental stimulation is for normal learning.

Puppies reared in isolation and not subjected to any sensory stimulations are unable to respond to dangerous features of their surroundings. Such puppies will put their nose into flames and they often hurt themselves by bumping into things and falling off heights. Rhesus infants kept in isolation show abnormal social behaviour, because of isolation they are being deprived of many .•stimulation and learning processes.

(v) Destruction of connections: If connections are destroyed experimentally or accidentally learning cannot reoccur. When certain connections of neurons are cut or divided in frontal lobes of dogs and rats these animals are unable to learn essential social relationships. They treat their fellow as objects, walking on them and taking food even from animals larger and stronger than themselves. Although they are bitten repeatedly, still they do not learn because of destruction of connections.

(vi) Learning and emotions: Learning is made far more effective if strong emotions are attached to it. It seems that stronger the emotions, the more firmly fixed learning would be. A child or chimp will learn just after receiving one prick to fear the needle.

2. Changes in the structure of neurons. The other hypothesis proposes

that main neurological changes during learning is not restricted to connectionsbut reverberation brings about permanent chemical changes in the nucleus of a neuron. It is believed, that the arriving nerve impulse causes electrochemical changes in a neuron, then these changes cause changes in the sequence of amino acids of DNA. Once this molecule has been given a new combination – that remains. This changed DNA alters the protein molecules of the entire neuron.

If a neuron is changed in this way by the arrival of nerve impulses, the change is permanent, It is suggested that this is how experience of learning affects neurons permanently, in other words, things are memorized for longer periods.

These views were worked out by Prof. Hyden (1976). He perfected a marvelous technique of micro-dissection of dissecting out cells and-parts of cells, and he also worked out ways of weighing this material and estimating its various chemical constituents. He showed that when neurons are stimulated- more protein is formed within the cell bodies.

In an experiment he took rats and divided them into two groups. The rats of one group were kept in dark and isolation, and other rats remained together normally and were also allowed to play and socialize . Examination of their brains showed that the group which was kept in dark in total isolation without sensory stimulations had little protein in the neurons of their brains, whereas, those which lived normally, exposed to all kinds of stimuli and subjected to learning had far more protein in their neurons. In another experiment a comparison was made in total number of dendrites between the trained and untrairied animals .The animals subjected to learning had more dendrites. Spinelli, Jensen and Di Prisco (1980) trained kittens to avoid mild electric shock and then they were examined for the neurons in their somato-sensory cortex. They found significant increase in the number and complexity of dendric branches.

11.4 Behaviour of domestic and Zoo animals

Captivity : Animals that live under human care in defined area, prevented with fence and cages are designated as " in **captivity"** . Captivity can be used as a generalizing term to describe the keeping of either domesticated animals (livestock and pets) or wild animals in zoo. This may include for example farms, private homes and zoos. There are three types of captive animals : Domestic, Pet and Wild (in zoo).

11.4.1 domestic, pet and zoo animals :

Domestic Animals:

The definition of domestic animal includes three types known as companion, livestock, and working animals. People have been domesticating animals under their control to gain economic benefits through agricultural purposes. Humans control their behaviours, feeding, and other biological requirements. People even manipulate the genetic backgrounds of domestic animals through selective breeding. Farm animals have been important to fulfill milk , meat ,eggs and protein requirements, and the dogs have been useful for protection, and large animals (viz. horses, elephants, donkeys… etc) have been vital for fulfilling working purposes.

The domestication of animals is the oldest documented instance of keeping animals in captivity. This process eventually resulted in habituation of wild animal species to survive in the company of human beings. Probably the earliest known domestic animal was the dog, likely as early as 15000 BC among hunter-gatherers in several locations. Many animals have been domesticated :

Animal	Where Domesticated	Date
Dog	Not known	14,000 BC
Sheep	Western Asia	8500 BC
Cat	Fertile Crescent	8500 BC
Goats	Western Asia	8000 BC
Pigs	Western Asia	7000 BC
Cattle	Eastern Sahara	7000 BC
Chicken	Asia	6000 BC
Elephants	Asia	2000 BC
Donkey	Northeast Africa	4000 BC
Horse	Kazakhstan	3600 BC

Silkworm	China	3500 BC
Camel	China or Mongolia	3500 BC
Honey Bee	Near East or Western Asia	3000 BC
Buffalo	Pakistan	2500 BC
Duck	Western Asia	2500 BC
Reindeer	Siberia	1000 BC
Ostrich	South Africa	AD 1866

(modified from source : Zeder MA. 2008. Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. Proceedings of the National Academy of Sciences 105(33):11597-11604).

Pet Animals

A pet animal is a household animal cared for either companionship or pleasure. Usually, there is an owner for the pet, and he/she treats the pet with care and affection. People do not keep pets for economic purposes, but they fall in love with their pet. The objective of keeping a pet or pets is mainly the companionship and recreation that owners find in their attractive and playful animals. Studies have shown that keeping pet animals has a relieving effect on stress, and it is an approved medical therapy. The most popular pets are dogs and cats, but other popular pets include rodents, spiders, birds, sometimes lizards and snakes.

Difference between Pet and Domestic Animals?

The following table summarizes the differences between pet and domestic animals.

Pet Animals	**Domestic Animals**
1. Kept for companionship , fun and recreation e.g. dogs, cats, rodents, some reptiles…	1.Kept for economic benefits e.g. sheep, cattle, buffalo, horse, elephant…

2. Very limited or no economic benefits	2. Always economically beneficial
3. Allowed to roam freely inside the house.	3. Not allowed inside the house
4.Very strong emotional relationship with the owner	4. emotional relationship with the owner is not as strong as in pets
5. Disease transmission to owner is common as there is direct contact	5.Disease transmission to care taker is possible but not common to owner

11..4.2 Benefit and cost to animals in zoo:

The first official Zoo appeared in 1828 for scientific study and was known as the London Zoological Gardens. In 1847 was opened for the public. By definition, a Zoo is a place where wild animals are kept for exhibition for the public.

(1) Zoos are, first and foremost, for people—not animals. Zoos exist to serve the human gaze and "most animals don't want to be stared at—that's stressful for them

(2) Zoo are used for us for - **Recreation and Education (**seeing rare and exotic animals)**, and for Conservation and Research.**

(3) **Captive breeding** and subsequent re-introduction of a threatened species is an important and in some cases very successful tool for species conservation. Captive breeding programs with the goal of reintroduction have existed since the 1960s.One of the first successful programs was the reintroduction of the Arabian oryx natives of Oman , they were hunted to extinction in the wild in 1972. he Phoenix Zoo (in Arizona) started a captive breeding program with 9 individuals and over 200 young were successfully bred. In 1982 they were reintroduced to Oman .Captive breeding saved the **Bison**, **Red Wolves** in Yellowstone, **Peregrine Falcon** ,Michigan, **Whooping cranes** ,USA ; **Golden-lion tamarins** in the Brazilian forests, **Pere Davids deer**, China

, **Przewalski's horse** has recently been re-introduced to the wild in Mongolia.

Delhi zoo has reported successful breeding of **Hoolock gibbon ,** Jaipur Zoo is known for captive breeding of **crocodiles and wolves.**

(4) Zoo cryo preserve rare gene stock for future use.

Besides this, there is tremendous cost/ harm involved to animals.

1. **Inbreeding: It** is a serious problem. It cuts down life span. eg Asian elephant in captivity lives for about 19 years, whereas, in wild it can live up to 41 years

2. Zoochosis:

- In 1992, Bill Travers, co-founder of the Born Free Foundation, first coined the term '**zoochosis**' to describe this obsessive, repetitive behaviour, and described zoo animals behaving abnormally as '**zoochotic**'.
- **Zoochosis** is the term coined for when an animal becomes deeply depressed, even psychotic, as the result of captivity.
- Zoochosis resulted from **putting animals in captivity in small enclosures** , as it is derived from the word zoo and psychosis, meaning a loss of contact with reality, which usually includes delusions and hallucinations.
- Zoochosis occurs because animals are not used to being in captivity as they belong in the wild.

Stereotyped Symptoms of Zoochosis-

- **Geophagia**; eating soil or sand.
- **Lignophagia**; eating wood.
- **Pica;** eating materials other than normal food.
- **Polydipsia;** excessive drinking.
- **Urine drinking**; drinking urine.
- **Stone chewing**; chewing stones or rocks without swallowing them
- **Pacing and circling:** Continuous walking back and forth or in a circle, following the same path. Signs of regular pacing include definite paths

worn in the ground. Seen in many captive animals, especially big cats and canids (eg wolves).

- **Tongue-playing and Bar-biting:** The continual licking, sucking or biting of walls, bars or gates in an enclosure. Often seen in giraffe and primates.
- **Head bobbing, Weaving and Swaying:** Standing in one place swaying the head and shoulders, even the whole body, from side to side, moving the head up and down, or weaving to and fro continuously. Seen in e.g. bears and elephants.
- **Neck twisting** :Unnatural twisting and rolling of the neck, often flicking the head around or bending the neck back. It is often combined with pacing behaviour. Seen in e.g. giraffe, llama, bears & primates.
- **Rocking:** Sitting, sometimes hugging the legs, rocking forwards and backwards. Seen in e.g. captive ape species.
- **Over grooming and Self Mutilation :** Self-inflicted physical harm, such as biting or chewing tail or leg, or hitting a head against a wall, grooming to an excessive extent, pulling out hair or feathers, often leaving bald patches, irritated and broken skin. Seen in e.g. apes, bears, parrots and big cats
- **Vomiting and Regurgitating :**A form of 'bulimia', the repeated vomiting, eating of vomit and regurgitation. May be linked to the captive diet. Seen in e.g. captive ape species.
- **Coprophilia and Coprophagia :**Playing with and eating of excrement (in species that do not naturally do this) or smearing faeces on enclosure walls and glass. Seen in e.g. captive primate species.
- **Activity anorexia**; a condition where animals exercise excessively while simultaneously reducing their food intake.
- **Cribbing or crib-biting**; grabbing a solid object such as a fence with the incisors, arching the neck, pulling against the object, and sucking in air.
- **Excessive vocalization**; vocalizing more frequently than expected.
- **Excessive aggression**; aggressive acts that are more frequent or of greater intensity than expected.
- **Excessive/submissive urination** (Polyuria); urinating more frequently than expected or under conditions where it would not be expected

- **Excessive licking;** excessive licking of the floor, wall or other environmental features.
- **Feather-plucking (Pterotillomania**); birds chewing, biting or plucking their own feathers with their beak, resulting in damage to the feathers and occasionally the skin. .
- **Trichotillomania;** an animal pulling out its own fur, hair or wool, often followed by eating it.
- **Self-injury**; an animal injuring its own body tissues.
- **Tail biting;** biting or chewing the tail of another animal.
- **Tail chasing;** an animal chasing its own tail in circles
- **Weaving;** repeatedly rocking backwards and forwards, or from side to side.

11..4.3 Enrichment of cages

To keep animals in captivity , it is very necessary to **enrich** their surroundings:

Enrichment involves any change to an animal's life or environment which is beneficial for welfare and which provides for appropriate and welfare, and which provides for appropriate and 'naturalistic' or 'wild' behavioural opportunities.

1. Keep animals in sufficiently spacious areas.
2. Social enrichment involves providing appropriate- pairings or groupings as per their social organizations.
3. Provide them Sensory enrichment by providing proper light, sound and smell.
4. Nutrition is also an important part of enrichment, and works by providing different types of food or different types of presentation.
5. Physical enrichment involves providing climbing frames, wooden logs, net, soft floor and even toys. Water tank for hippo, rubbing posts for the rhinos , Netting, green tree, dried trees for birds in aviary, Wooden logs, hollow trunk trees and pots for snakes .
6. Cognitive enrichment can be provided for by incorporating problem solving activities with some primate species. It can improve brain development and function. It can also enhance learning and memory and improve an animal's interaction with its environment.

Environmental enrichment may also promote reproduction, as a result of increased physical and psychological well being. What is important is that enrichment is implemented in a pro-active way (prior to a potential abnormal behaviour occurring).

Confining animals in cages is pathetic, the best way is to have open zoo, where animals roam in their natural habitat and people sit in a vehicle to watch them.

11.5 Summary

This unit describes learning and memory its introduction and definition, types habituation, trial and error, conditioning, cognition, imprinting; short and long term memory, neural mechanism of learning and lastly behaviour of domestic and Zoo animals.

Learning is a process which manifests itself in an individual's behaviour as a result of experience. Learning ability has its control by genes but learned processes in an individual's lifetime are not genetically transferred. Learning has been classified as Flexible - Habituation , Conditioning , Trail and Error, cognition and Restricted - Imprinting . Habituation is the simplest form of learning. Habituation like phenomena is found in every group of animals from Weevil to Whales. Habituation is important for adjusting an animal's behavior to its environment. By habituation animals learn to conserve energy and time by not responding to an irrelevant stimulus. Learning by trial and error has basic instincts or motivation or drive or urge associated with it. When animals are motivated by thirst, hunger, sex or fear they show restlessness, and appetitive behavior - during the course of which it performs spontaneously a variety of motor patterns . If one of these patterns is followed by reinforcement this association is repeated the animal learns to perform a pattern regularly to that particular situation. Pavlovian conditioning is flexible and steer animals through their changing environments by means of signs, sounds, smells.

Higher faculty of learning associated with intelligence is found in certain animals. Chimps-our closest relatives among non-human primates-are capable of many forms of complex cognition. Often they perform cognitive tasks in ways that are strikingly similar to humans. Lastly there is Imprinting. It is a process which occurs at a an early age. So is also called early childhood learning.

Then comes Short and long term memory and neural mechanism of learning .

First of all you must know what is memory? Memory is consolidation of learned processes. STM means very recent memories, usually measured in minutes-to-days , whereas, LTM is formed by permanent changes in cell contents/ organelles. Conversion of STM to LTM is called consolidation.

What neural mechanism is involved in memory?

According to this correlation, cortex appeared to be the seat of memory.

Lashley formulated "Principle of Equipotentiality" , it is experimentally proved that corpus callosum, limbic system, hippocampus, hypothalamus, pons are also involved in memory. It is generally agreed that while we memorize things two major changes take place first - Change in the connections between neurons and subsequently changes take place in the structure of neurons.

Last part of this unit deals with behaviour of domestic and Zoo animals, benefit and cost to animals in zoo , causing Inbreeding and Zoochosis**.**

11.6 Glossary

- **Eidetikers or Mnemonists:** People having Photographic memory
- **Learning :** Learning is a general term for all behavioural changes affected by experience. New neural circuits are formed for its execution.
- **Habituation** : Habituation is important for adjusting an animal's behavior to its environment. By habituation animals learn to conserve energy and time by not responding to an irrelevant stimulus.
- **Trial and Error Learning:** Learning by trial and error has basic instincts or motivation or drive or urge associated with it. When animals are motivated by thirst, hunger, sex or fear they show restlessness, and exploratory or appetitive behavior - during the course of which it performs spontaneously a variety of motor patterns viz- sniffing, walking and looking around. If one of these patterns is followed by reinforcement e.g. a hungry animal while exploring the surroundings receives food and if this association is repeated the animal learns to perform a pattern regularly to that particular situation.
- **Simple Reflex** : A simple reflex and a conditioned reflex are two different things. A simple reflex is the simplest automatic functional unit of the nervous system capable of detecting change and cause a response to that change. Many body activities are controlled reflexly. This term

implies an automatic adjustment to maintain homeostasis without conscious effort. Simple reflex are also known as inborn or unconditioned reflexes.

- **Conditioning or Conditioned Reflex or Pavlovian conditioning:** whereas, the conditioned reflexes are acquired reflexes. They are not transmitted through genes. They can be established or abolished.
- They are always established upon some pre-existing unconditioned reflexes.
- **Cognition:** Includes higher faculty of learning eg perception and decision making . Animals solve problems to find an escape route, to reach hanging bananas, use a stick to take out termites from hole, use a wooden log to cross water, showing higher mental capabilities like **"insight"** means the ability to notice and understand a situations, **"reasoning"** means the ability to combine spontaneously two or more separate experiences to formulate a new
- activity, which is effective for achieving a desired goal" and "**intelligence"** means the ability to recognize a problem, formulate a solution and act upon it.
- These faculties have been seen in mammals and most in non human primates. They are of course best developed in human beings.
- **Imprinting: (Form of early childhood learning) :** It is a a learning process which occurs at a an early age. **Konrad Lorenz** (1935) was the first one to notice this, there are phases of an animal's life when they are likely to be sensitive for some typical learning processes , this period of time is known as "critical period" or "sensitive phase".
- **Precocial** : start moving soon after hatching / birth e.g. Spiny mouse, hoofed mammals, ducks, mallards, geese
- **Nidifugous chick :** Born with feathers eyes open and move immediately
- **Altricial:** Do not move immediately e.g. house sparrow, ring dove, pigeon
- **Nidicolus chick:** Born naked, blind and do not move.

- **Law of Effort :** Proposed by Hess, that imprinting is stronger if the chick has to cross hurdles , if the model is noisy , if the following path is raised .
- **Deprived syndrome ;** H. F. Harlow had proposed this after conducting isolation experiments on rhesus infants raised away from their mother.
- They showed serious behavioral disturbances.
- **Memory:** It is the process in which learned information is, stored and retrieved whenever necessary.
- **Short Term Memory (STM) : V**ery recent memories, usually measured in minutes-to-days. Short-term memory has a fairly limited capacity; it can hold about seven items for no more than 20 or 30 seconds at a time. The message runs in the form of electrical current.
- **Reverberation** : Electrical current in STM keeps moving on and on automatically for a certain period of time .
- **Consolidation :** If reverberation takes place for certain period of time STM changes to LTM, its called consolidation.
- **Long Term Memory** : After reverberation and consolidation, permanent changes are brought about in protein of neuron, once this happens its is called LTM, it is almost permanent , it can store vast amounts of information .

- **Principle of Equipotentiality :** Lashley observed that in rats ability to learn were affected in proportion to the size of the cortical ablation he made in their brains ; the larger the ablation the poorer was the ability to learn , he called it Principle of Equipotentiality .
- **Captivity :** Animals that live under human care in defined area, prevented with fence and cages are designated as " in **captivity"** .
- **Domestic Animals:** kept as livestock, and as working animals in farm.
- **Pet Animals:** A pet animal is a household animal cared for either companionship , amusement and for pleasure.

- **Zoochosis:** Repetitive behaviour, and described zoo animals behaving abnormally as '**zoochotic',** Zoochosis is the term coined for when an animal becomes deeply depressed, even psychotic, as the result of captivity.
- **Geophagia**; Eating soil or sand by animals.
- **Lignophagia**; Eating wood by animals.
- **Pica;** Eating materials other than normal food by animals.
- **Polydipsia;** Excessive drinking by animals.
- **Rocking:** Sitting, sometimes hugging the legs, rocking forwards and backwards. Seen in. captive ape species.
- **Coprophilia and Coprophagia :**Playing with and eating of excrement (in species that do not naturally do this) or smearing faeces on enclosure walls and glass. Seen in captive primate species.
- **Activity anorexia**; A condition where animals exercise excessively while simultaneously reducing their food intake.
- **Cribbing or crib-biting**; Grabbing a solid object such as a fence with the incisors, arching the neck, pulling against the object, and sucking in air.
- **Feather-plucking (Pterotillomania**); Birds chewing, biting or plucking their own feathers with their beak, resulting in damage to the feathers and occasionally the skin. .
- **Trichotillomania;** An animal pulling out its own fur, hair or wool, often followed by eating it..

11.7 Self-Learning Exercise

Section -A (Very Short Answer Type)

1. Learning is Innate T/F
2. Imprinting is

(i) Early childhood learning
(ii) Early childhood instinct
(iii) Early childhood conditioning
(iv) Early childhood habituation

3. Mnemonists are

(i) People with lost memory called Eidetickers

(ii) People with photographic memory called Eidetickers
(iii) People with No hippocampus
(iv) People with Hippocampus
4. When animal lerns not to respond to neutral stimulus it is called
(i) Trial and error
(ii) Conditioning
(iii) Habituation
(iv) Cognition
5. Thorndike had proposed learning by
(i) Insight
(ii) Reasoning
(iii) Trial and error
(iv) Imprinting
6. Pavlov discovered the phenomenon of
(i) ognition
(ii) Insight
(iii) Reasoning
(iv) Conditioning
7. Sensitive period is characteristic of
(i) Memory
(ii) Reverberation
(iii) Consolidation
(iv) Imprinting
8. Animals that start moving soon after hatching are called Altricial T/F
9. Nidicolous chicks are Altricial T/F
10. Law of effort was proposed by …………….
11. Harlow had proposed symptoms of ……..
12. In STM messages run in the form of electrical current T/F
13. Repeated circulation of electrical message in neural circuit is the property of STM T/F
14. Conversion of STM to STM is called ……
15. Repetitive behaviour in captive animals is a sign of ………

Section -B (Short Answer Type)

1 Differentiate between Learning and Instinct

2 Differentiate between STM and LTM

3 Differentiate between Reverberation and consolidation

4 Differentiate between Habituation and conditioning

5. Write Bad effect of captivity on animals

Section -C (Long Answer Type)

1. Define learning.name different types , elaborate on conditioning
2. Explain Imprinting with suitable examples
3. Describe neural mechanism of learning
4. Differentiate between domestic and zoo animals, add a note on zoochosis

Answer Key of Section-A

1 F

2 i

3 ii

4 iii

5 iii

6 iv

7 F

8 T

9 T

10 Hess

11 Deprivation syndrome

12 T

13 T

14 consolidation

15 Zoochosis

Unit-12

Basic Concepts of Development

Structure of the Unit

12.0 Objectives

After going through this unit you will be able to understand

- What are the basic concepts of development?

- What is cell fate and cell lineages?
- Experiments regarding genomic equivalence and the cytoplasmic determinants?
- What is genomic imprinting and its mechanism?

12.1 Introduction

Developmental biology is the study of the process by which animals and plants grow and develop, and is synonymous with ontogeny. In animals most development occurs in embryonic life, but it is also found inregeneration, asexual reproduction and metamorphosis, and in the growth and differentiation of stem cells in the adult organism. In plants, development occurs in embryos, during vegetative reproduction, and in the normal outgrowth of roots, shoots and flowers. Practical outcomes from the study of animal developmental biology have included in vitro fertilization, now widely used in fertility treatment, the understanding of risks from substances that can damage the fetus (teratogens), and the creation of various animal models for human disease which are useful in research. Developmental Biology has also helped to generate modern stem cell biology which promises a number of important practical benefits for human health.

Developmental Biology is a fundamental aspect of biology. Development depends upon complex mechanisms and many layers of "biological information" that are superimposed one upon another. As our techniques improve, developmental biology has the potential to be much better understood.

Once, developmental biology was mostly descriptive (ie. descriptive/comparative embryology).

Modern developmental biology is mostly experimental. Recent advances in cell biology, genetics and molecular biology has and will continue to further our understanding of development unlike any time in the past.

Embryogenesis (embryo formation) determines the overall body plan. Organogenesis (organ formation) determines subsections of the body (examples: vertebrate limb, Drosophila eye).

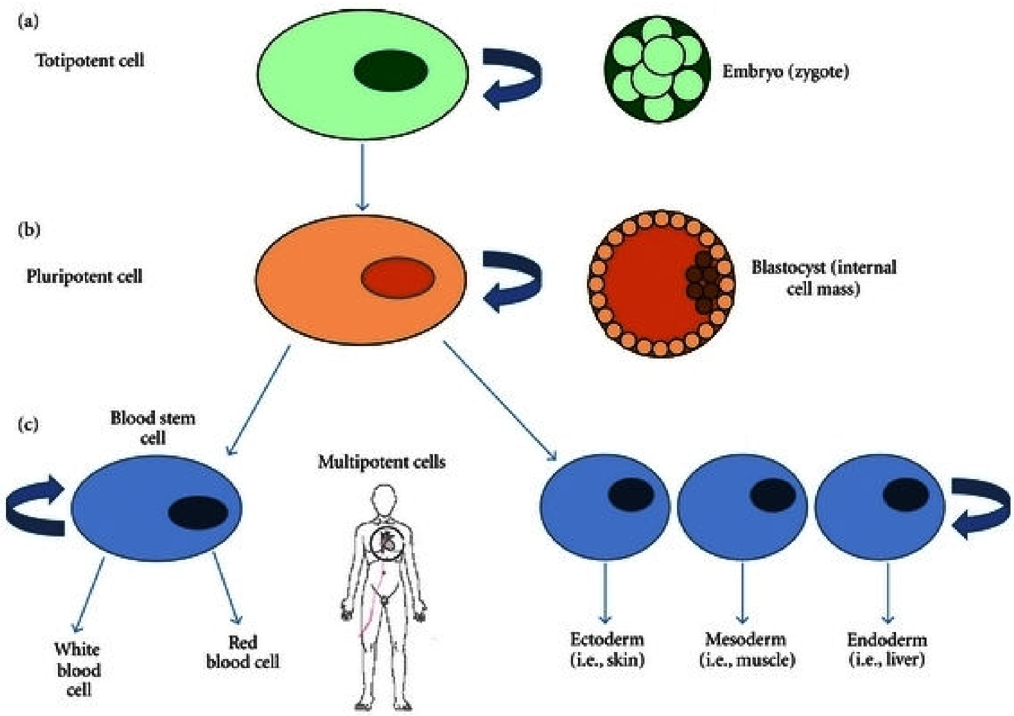
Often these processes share much more than is first obvious. Many genes, proteins, signal transduction pathways and cell behaviours are common to both processes.

12.2 Cell potency

Cell potency is a cell's ability to differentiate into other cell types. The more cell types a cell can differentiate into, the greater its potency. Potency is also described as the gene activation potential within a cell which like a continuum begins with totipotency to designate a cell with the most differentiation potential,pluripotency, multipotency, oligopotency and finally unipotency. Potency is taken from the Latin term "potens" which means "having power."

12.2.1 Totipotency

When a single cell have complete potential to convert into complete organism. This is the ability of a single cell to divide and produce all of the differentiated cells in an organism.Spores and Zygotes are examples of totipotent cells. In the spectrum of cell potency, totipotency represents the cell with the greatest differentiation potential. *Toti* comes from the Latin *totus* which means "entirely."



It is possible for a fully differentiated cell to return to a state of totipotency the process is known as **de-differentiation**. This conversion to totipotency is complex, not fully understood and the subject of recent research. Stem cells resembling totipotent blastomeres from 2-cell stage embryos can arise spontaneously in the embryonic stem cell cultures.

The human development model is one which can be used to describe how totipotent cells arise. Human development begins when a sperm fertilizes an egg and the resulting fertilized egg creates a single totipotent cell, a zygote. In the first hours after fertilization, this zygote divides into identical totipotent cells, which can later develop into any of the three germ layers of a human (endoderm, mesoderm, or ectoderm), into cells of the cytotrophoblast layer or syncytiotrophoblast layer of the placenta. After reaching a 16-cell stage, the totipotent cells of the morula differentiate into cells that will eventually become either the blastocyst's Inner cell mass or the outer trophoblasts. Approximately four days after fertilization and after several cycles of cell division, these totipotent cells begin to specialize. The inner cell mass, the source of embryonic stem cells, becomes pluripotent.

Research on *Caenorhabditis elegans* suggests that multiple mechanisms including RNA regulation may play a role in maintaining totipotency at different stages of development in some species.

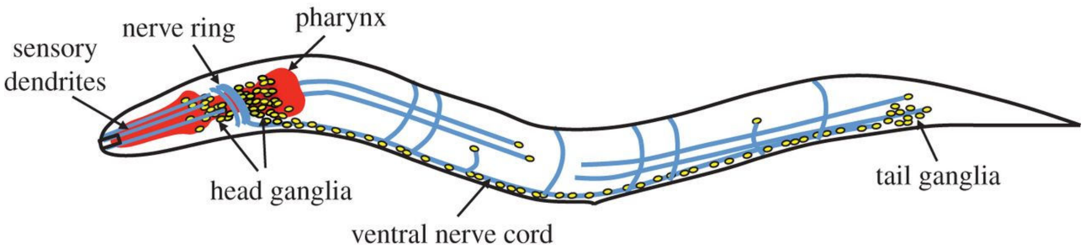


Figure - *Caenorhabditis elegans*

12.2.2 Pluripotency

This is the potential of a single cell to convert into more then one type of cell. In cell biology, pluripotency (from the Latin plurimus, meaning very many, and potens, meaning having power) refers to a stem cell that has the potential to differentiate into any of the three germ layers: endoderm (interior stomach lining, gastrointestinal tract, the lungs), mesoderm (muscle, bone, blood, urogenital), or ectoderm (epidermal tissues and nervous system). However, cell pluripotency is a continuum, ranging from the completely pluripotent cell that can form every cell of the embryo proper, e.g., embyronic stem cells, to the incompletely or partially pluripotent cell that can form cells of all three germ layers but that may not exhibit all the characteristics of completely pluripotent cells.

12.2.3 Oligopotency

In biology, oligopotency is the ability of progenitor cells to differentiate into a few cell types. It is a degree of potency. Examples of oligopotent stem cells are the lymphoid or myeloid stem cells. A lymphoid cell specifically, can give rise to various blood cells such as B and T cells, however, not to a different blood cell type like a red blood cell. Examples of progenitor cells are vascular stem cells that have the capacity to become both endothelial or smooth muscle cells.

12.2.4 Unipotency

In cell biology, a unipotent cell is the concept that one stem cell has the capacity to differentiate into only one cell type. It is currently unclear if true unipotent stem cells exist. Hepatoblasts, which differentiate into hepatocytes (which constitute most of the liver) or cholangiocytes (epithelial cells of the bile duct), are bipotent.

12.3 Cell fate and cell lineages

Within the field of developmental biology one goal is to understand how a particular cell (or embryo) develops into the final cell type (or organism), essentially how a cell's fate is determined. Within an embryo, 4 processes play out at the cellular and tissue level to essentially create the final organism. These processes are **cell proliferation, cell specialization, cell interaction and cell movement**. Each cell in the embryo receives and gives cues to its neighboring cells and retains a cell memory of its own cell proliferation history. Almost all animals undergo a similar sequence of events during embryogenesis and have, at least at this developmental stage, the three germ layers and undergo gastrulation.

scientists discovered that a basic set of the same proteins and mRNAs are involved in all of embryogenesis. This is one of the reasons that model systems such as the fly (*Drosophila melanogaster*), the mouse (Muridae), and the leech (Helobdella), can all be used to study embryogenesis and developmental biology relevant to other animals, including humans. What continues to be discovered and investigated is how the basic set of proteins (and mRNAs) are expressed differentially between cells types, temporally and spatially; and whether this is responsible for the vast diversity of organisms produced. This leads to one of the key questions of developmental biology of how is cell fate determined.

12.3.1 Cell fate

Which cell will convert into which organ is known as cell fate and it's determined during the early embryonic stages. The development of new molecular tools and major advances in optical microscopy have made cell lineageication in the *C. elegans* embryo. This technique is used to study cells as they are differentiating into their final cell fates. Merely observing a cell as it becomes differentiated during embryogenesis provides no indication of the mechanisms that drive the specification. Therefore, the addition of molecular manipulation techniques, including gene and protein knock downs, knock outs and overexpression, along with live cell imaging techniques has been transformational in understanding what mechanisms are involved with cell fate determination. Transplantation experiments are commonly used in conjunction with the genetic manipulation and lineage tracing. Transplantation experiments are the only way to determine what state the cell is in on its way to being differentiated.

For a number of cell cleavages (the specific number depends on the type of organism) all the cells of an embryo will be morphologically and developmentally equivalent. This means, each cell has the same development potential and all cells are essentially interchangeable, thus establishing an equivalence group. The developmental equivalence of these cells is usually established via transplantation and cell ablation experiments.

The determination of a cell to a particular fate can be broken down into two states where the cell can be specified (committed) or determined. In the state of being committed or specified, the cell type is not yet determined and any bias the cell has toward a certain fate can be reversed or transformed to another fate. If a cell is in a determined state, the cell's fate cannot be reversed or transformed. In general, this means that a cell determined to differentiate into a brain cell cannot be transformed into a skin cell. Determination is followed by differentiation, the actual changes in biochemistry, structure, and function that result in specific cell types. Differentiation often involves a change in appearance as well as function.

12.4 Modes of Specification

There are three general ways a cell can become specified for a particular fate; they are autonomous specification, conditional specification and syncytial specification.

12.4.1 Autonomous Specification

The cell itself determine which form they want to convert. This type of specification results from cell-intrinsic properties; it gives rise to mosaic development. The cell-intrinsic properties arise from a cleavage of a cell with asymmetrically expressed maternal cytoplasmic determinants (proteins, small regulatory RNAs and mRNA). Thus, the fate of the cell depends on factors secreted into its cytoplasm during cleavage.

Positive feedback can create asymmetry from homogeneity. In cases where the external or stimuli that would cause asymmetry are very weak or disorganized, through positive feedback the system can spontaneously pattern itself. Once the feedback has begun, any small initial signaling is magnified and thus produces an effective patterning mechanism. This is normally what occurs in the case of lateral inhibition in which neighboring cells induce specification via inhibitory or inducing signals. This kind of positive feedback at the single cell level and tissue level is responsible for symmetry breaking, which is an all-or-none process whereas once the symmetry is broken, the cells involved become very different. Symmetry breaking leads to a bistable or multistable system where the cell or cells involved are determined for different cell fates. The determined cells continue on their particular fate even after the initial stimulatory/inhibitory signal is gone, giving the cells a memory of the signal.

12.4.2 Conditional Specification

In contrast to the autonomous specification, this type of specification is a cell-extrinsic process that relies on cues and interactions between cells or from concentration-gradients of morphogens. Inductive interactions between neighboring cells is the most common mode of tissue patterning. In this mechanism, one or two cells from a group of cells with the same developmental potential are exposed to a signal (morphogen) from outside the group. Only the cells exposed to the signal are induced to follow a different developmental pathway, leaving the rest of the equivalence group unchanged. Another mechanism that determines the cell fate is regional determination. As implied by the name, this specification occurs based on where within the embryo the cell is positioned, it is also known as positional value. This was first observed when mesoderm was taken from the prospective thigh region of a chick embryo, was grafted onto the wing region and did not transform to wing tissue, but instead into toe tissue.

12.4.3 Syncytial Specification

This type of a specification is a hybrid of the autonomous and conditional that occurs in insects. This method involves the action of morphogen gradients within the syncytium. As there are no cell boundaries in the syncytium, these morphogens can influence nuclei in a concentration-dependent manner.

12.5 Differential gene expression and development

The fate of a cell describes what it will become in the course of normal development. The fate of a particular cell can be discovered by labelling that cell and observing what structures it becomes a part of. When the fate of all cells of an embryo has been discovered, we can build a fate map, which is a diagram of that organism at an early stage of development that indicates the fate of each cell or region at a later stage of development.

The **developmental potential**, or potency, of a cell describes the range of different cell types it can become. The zygote and its very early descendents are totipotent - these cells have the potential to develop into a complete organism. Totipotency is common in plants, but is uncommon in animals after the 8-16 cell stage. As development proceeds, the developmental potential of individual cells decreases until their fate is determined.

The **determination** of different cell types (cell fates) involves progressive restrictions in their developmental potentials. When a cell “chooses” a particular fate, it is said to be determined, although it still "looks" just like its undetermined neighbors. Determination implies a stable change - the fate of determined cells does not change.

Differentiation follows determination, as the cell elaborates a cell-specific developmental program. Differentiation results in the presence of cell types that have clear-cut identities, such as muscle cells, nerve cells, and skin cells.

12.6 Morphogenetic gradient

During early development, morphogen gradients result in the differentiation of specific cell types in a distinct spatial order. The morphogen provides spatial information by forming a concentration gradient that subdivides a field of cells by inducing or maintaining the expression of different target genes at distinct concentration thresholds. Thus, cells far from the source of the morphogen will receive low levels of morphogen and express only low-threshold target genes. In contrast, cells close to the source of morphogen will receive high levels of morphogen and will express both low- and high-threshold target genes. Distinct cell types emerge as a consequence of the different combination of target gene expression. In this way, the field of cells is subdivided into different types according to their position relative to the source of the morphogen. This is a general mechanism by which cell type diversity can be generated in embryonic development in animals.

Some of the earliest and best-studied morphogens are transcription factors that diffuse within early *Drosophila melanogaster* (fruit fly) embryos. However, most morphogens are secreted proteins that signal between cells.

A morphogen spreads from a localized source and forms a concentration gradient across a developing tissue. In developmental biology, 'morphogen' is rigorously used to mean a signalling molecule that acts directly on cells (not through serial induction) to produce specific cellular responses that depend on morphogen concentration. This definition concerns the mechanism, not any specific chemical formula, so simple compounds such as retinoic acid (the active metabolite ofretinol or vitamin A) may also act as morphogens.

Well known mammalian morphogens include retinoic acid, sonic hedgehog (SHH), transforming growth factor beta (TGF-β)/bone morphogenic protein (BMP), andWnt/beta-catenin. Morphogens in *Drosophila* include decapentaplegic and hedgehog.

During development, retinoic acid, a metabolite of vitamin A, is used to stimulate the growth of the posterior end of the organism. Retinoic acid binds to retinoic acid receptors that acts as transcription factors to regulate the expression of Hox genes. Exposure of embryos to exogenous retinoids especially in the first trimester results in birth defects.

TGF-β family members are involved in dorsoventral patterning and the formation of some organs. Binding to TGF-β to type II TGF beta receptors recruits type I receptors causing the latter to be transphosphorylated. The type I receptors activate Smad proteins that in turn act as transcription factors that regulate gene transcription.

Sonic hedgehog (Shh) are morphogens that are essential to early patterning in the developing embryo. Shh binds to the Patched receptor which in the absence of Shh inhibits the Smoothened receptor. Activated smoothened in turn causes Gli1, Gli2, and Gli3 to be translocated into the nucleus where they activate target genes such at PTCH1 and Engrailed.

genomic equivalence and the cytoplasmic determinants

12.7 Evidences of Genomic Equivalence

The other major objection to a genetically based embryology still remained: How could nuclear genes direct development when they were the same in every cell type? The existence of this **genomic equivalence** was not so much proved as assumed (because every cell is the mitotic descendant of the fertilized egg), so one of the first problems of developmental genetics was to determine whether every cell of an organism indeed had the same set of genes, or**genome**, as every other cell.

12.7.1 Metaplasia

The first evidence for genomic equivalence came from embryologists studying the regeneration of excised tissues. The study of salamander eye regeneration demonstrated that even adult differentiated cells can retain their potential to produce other cell types. Therefore, the genes for these other cell types' products must still be present in the cells, though not normally expressed. In the salamander eye, removal of the neural retina promotes its regeneration from the pigmented retina, and if the lens is removed, a new lens can be formed from the cells of the dorsal iris. The regeneration of lens tissue from the iris has been intensively studied.

These events are not the normal route by which the vertebrate lens is formed. The lens normally develops from a layer of head epithelial cells induced by the underlying retinal precursor cells. The formation of the lens by the differentiated cells of the iris is an example of **metaplasia** (or **transdifferentiation**), the transformation of one differentiated cell type into another. The salamander iris, then, has not lost any of the genes that are used to differentiate the cells of the lens.

12.7.2 Amphibian cloning

The ultimate test of whether the nucleus of a differentiated cell has undergone any irreversible functional restriction is to have that nucleus generate every other type of differentiated cell in the body. If each cell's nucleus is identical to the zygote nucleus, then each cell's nucleus should be **totipotent** (capable of directing the entire development of the organism) when transplanted into an activated enucleated egg. Before such an experiment could be done, however, three techniques for transplanting nuclei into eggs had to be perfected: (1) a method for enucleating host eggs without destroying them; (2) a method for isolating intact donor nuclei; and (3) a method for transferring such nuclei into the host egg without damaging either the nucleus or the oocyte.

All three techniques were developed in the 1950s by Robert Briggs and Thomas King. First, they combined the enucleation of the host egg with its activation. When an oocyte from the leopard frog (*Rana pipiens*) is pricked with a clean glass needle, the egg undergoes all the cytological and biochemical changes associated with fertilization. The internal cytoplasmic rearrangements of fertilization occur, and the completion of meiosis takes place near the animal pole of the cell. The meiotic spindle can easily be located as it pushes away the pigment granules at the animal pole, and puncturing the oocyte at this site causes the spindle and its chromosomes to flow outside the egg. The host egg is now considered both activated (the fertilization reactions necessary to initiate development have been completed) and enucleated. The transfer of a nucleus into the egg is accomplished by disrupting a donor cell and transferring the released nucleus into the oocyte through a micropipette. Some cytoplasm accompanies the nucleus to its new home, but the ratio of donor to recipient cytoplasm is only $1:10^5$, and the donor cytoplasm does not seem to affect the outcome of the experiments. In 1952, Briggs and King, using these techniques, demonstrated that blastula cell nuclei could direct the development of complete tadpoles when transferred into the oocyte cytoplasm.

12.7.3 Cloning mammals

In 1997, Ian Wilmut announced that a sheep had been cloned from a somatic cell nucleus from an *adult* female sheep. This was the first time that an adult vertebrate had been successfully cloned from another adult. To do this, Wilmut and his colleagues 1997 took cells from the mammary gland of an adult (6-year-old) pregnant ewe and put them into culture. The culture medium was formulated to keep the nuclei in these cells at the resting stage of the cell cycle (G_0). They then obtained oocytes (the maturing egg cell) from a different strain of sheep and removed their nuclei. The fusion of the donor cell and the enucleated oocyte was accomplished by bringing the two cells together and sending electrical pulses through them. The electric pulses destabilized the cell membranes, allowing the cells to fuse together. Moreover, the same pulses that fused the cells activated the egg to begin development. The resulting embryos were eventually transferred into the uteri of pregnant sheep. Of the 434 sheep oocytes originally used in this experiment, only one survived: Dolly. DNA analysis confirmed that the nuclei of Dolly's cells were derived from the strain of sheep from which the donor nucleus was taken. Thus, it appears that the nuclei of adult somatic cells can be totipotent. No genes necessary for development have been lost or mutated in a way that would make them nonfunctional.

12.8 Genomic imprinting

Genomic imprinting is the epigenetic phenomenon by which certain genes are expressed in a parent-of-origin-specific manner. If the allele inherited from the father is imprinted, it is thereby silenced, and only the allele from the mother is expressed. If the allele from the mother is imprinted, then only the allele from the father is expressed. Forms of genomic imprinting have been demonstrated in fungi, plants and animals.

In diploid organisms (like humans), the somatic cells possess two copies of the genome, one inherited from the father and one from the mother. Each autosomal gene is therefore represented by two copies, or alleles, with one copy inherited from each parent at fertilization. For the vast majority of autosomal genes, expression occurs from both alleles simultaneously. In mammals, however, a small proportion (<1%) of genes are imprinted, meaning that gene expression occurs from only one allele.

12.8.1 Imprinted genes in mammals

That imprinting might be a feature of mammalian development was suggested in breeding experiments in mice carrying reciprocal chromosomal translocations.Nucleus transplantation experiments in mouse zygotes in the early 1980s confirmed that normal development requires the contribution of both the maternal and paternal genomes. The vast majority of mouse embryos derived from parthenogenesis (called parthenogenones, with two maternal or egg genomes) andandrogenesis (called androgenones, with two paternal or sperm genomes) die at or before the blastocyst/implantation stage. In the rare instances that they develop to postimplantation stages, gynogenetic embryos show better embryonic development relative to placental development, while for androgenones, the reverse is true.

No naturally occurring cases of parthenogenesis exist in mammals because of imprinted genes. However, in 2004, experimental manipulation by Japanese researchers of a paternal methylation imprint controlling the *Igf2* gene led to the birth of a mouse (named Kaguya) with two maternal sets of chromosomes, though it is not a true parthenogenone since cells from two different female mice were used. The researchers were able to succeed by using one egg from an immature parent, thus reducing maternal imprinting, and modifying it to express the gene Igf2, which is normally only expressed by the paternal copy of the gene.

Parthenogenetic/gynogenetic embryos have twice the normal expression level of maternally derived genes, and lack expression of paternally expressed genes, while the reverse is true for androgenetic embryos. It is now known that there are at least 80 imprinted genes in humans and mice, many of which are involved in embryonic and placental growth and development. Hybrid offspring of two species may exhibit unusual growth due to the novel combination of imprinted genes.

Various methods have been used to identify imprinted genes. In swine, Bischoff *et al.* 2009 compared transcriptional profiles using short-oligonucleotide microarrays to survey differentially expressed genes between parthenotes (2 maternal genomes) and control fetuses (1 maternal, 1 paternal genome). An intriguing study surveying the transcriptome of murine brain tissues revealed over 1300 imprinted gene loci (approximately 10-fold more than previously reported) by RNA-sequencing from F1 hybrids resulting from reciprocal crosses. The result however has been challenged by others who claimed that this is an overestimation by an order of magnitude due to flawed statistical analysis.

In domesticated livestock, single-nucleotide polymorphisms in imprinted genes influencing foetal growth and development have been shown to be associated with economically important production traits in cattle, sheep and pigs.

12.8.2 Imprinting mechanisms

Imprinting is a dynamic process. It must be possible to erase and re-establish imprints through each generation so that genes that are imprinted in an adult may still be expressed in that adult's offspring. (For example the maternal genes that control insulin production will be imprinted in a male but will be expressed in any of the male's offspring that inherit these genes.) The nature of imprinting must therefore be epigenetic rather than DNA sequence dependent. In germline cells the imprint is erased and then re-established according to the sex of the individual, i.e. in the developing sperm (during spermatogenesis), a paternal imprint is established, whereas in developing oocytes (oogenesis), a maternal imprint is established. This process of erasure and reprogramming is necessary such that the germ cell imprinting status is relevant to the sex of the individual. In both plants and mammals there are two major mechanisms that are involved in establishing the imprint; these are DNA methylation and histone modifications.

Recently, a new study has suggested a novel inheritable imprinting mechanism in humans that would be specific of placental tissue and that is independent of DNA methylation (the main and classical mechanism for genomic imprinting). Among the hypothetical explanations for this exclusively human phenomenon, two possible mechanisms have been proposed: either a histone modification that confers imprinting at novel placental-specific imprinted *loci* or, alternatively, a recruitment of DNMTs to these loci by a specific and unknown transcription factor that would be expressed during early trophoblast differentiation.

A fertilized egg is called a:

a) germ cell b) embryo

c) zygote d) blastulae

2. **The process by which developing cells achieve their functional, mature identity as liver, or muscle, or nerve is called:**

a) cleavage division b) pattern formation

c) morphogenesis d) differentiation

3. **The process of commitment proceeds in which of the following ways:**

a) differentiation —> specification —> determination

b) determination —> specification —> differentiation

c) determination —> differentiation —> specification

d) specification —> determination —> differentiation

4. What is autonomous specification?

5. Describe the genomic imprinting?

6. What is cell fates and lineages?

7. Briefly describe the modes of specifications?

8. Gives evidences in support of genomic equivalence?

Unit - 13

Gametogenesis, Fertilization and Early Development

Structure of the Unit

13.0 Objectives

After going through this unit you will be able to understand

- How formation of oocytes and sperm cells take place during the process of gamatogenesis.

- Major steps involved for accomplishment of fertilization process in different species
- Fundamental types of cleavage in embryo.
- In early embryonic development how balstula and gastrulation stages establish Fate of blastopore (deuterostom, protostome) and blastomere (determinate, Indeterminate) and formation of germ layer in embryo

13.1 Introduction

This is the most interesting lesson for a student to read about development process of early embryo which leads to an organism. As beginners, let's start from very basic, all animals have male and female sex gonad, ovum and sprems formation and their fertilization to produce zygote which is fundamental in understanding the development of an animal

Then comes the cleavages which are classified based on amount of egg present in egg. During the course of early devlopment , animals acquired several stages all of which fall at different fixed time. During development of embryo, what does blastopore form mouth or anus? Accordingly animals are classified under two categories-deuterostom and protostome.There are embryos in which fate of blastopore is predetermined i.e. what these cells will make as embryo grows and in some it's not determined.

lastly, you will learn, how germ layer is derived to form part of different organs. Learn all this , in this fundamental chapter.

You will be able to describe the events take place in formation of ovum, sperm ovulation, fertilization and development of blastula and grastulation and thus the time when major development take place.

13.2 Gametogenesis

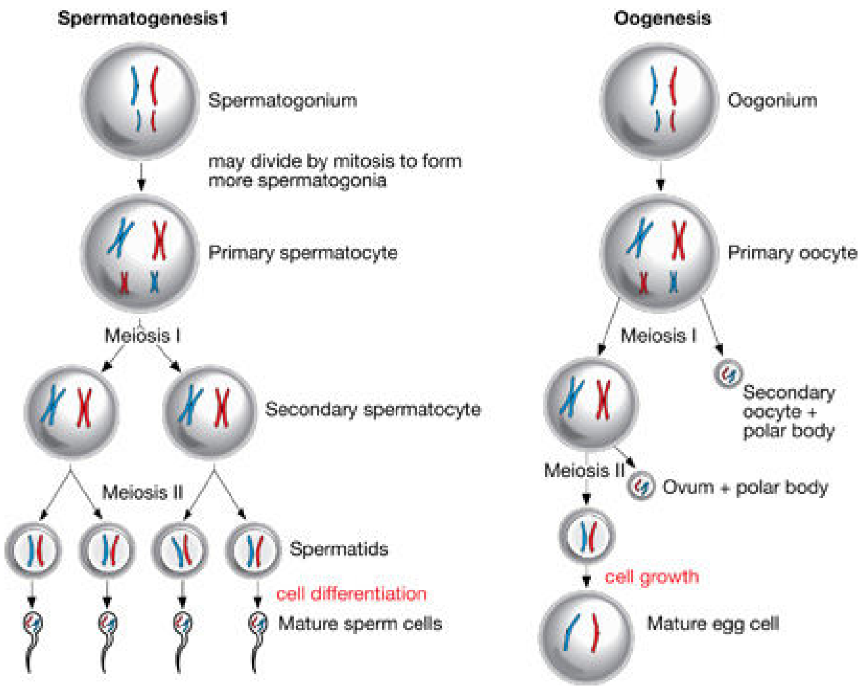
Gametogenesis is the formation of sex cells or reproductive cells or gametes. It happens in primary sex organs called gonads. The male and female gonads, namely the testis and ovary contain primordial germ cells. These cells are responsible for the production of gametes.

13.2.1 Spermatogenesis

The process in the development of spermatids from involved primordial male germ cells and their differentiation into spermatozoa is called **spermatogenesis**. In the testis of vertebrates, the specialised tissue for the process of spermatogenesis are located in the seminiferous tubules. The primordial germ cells of these tubules produce cells which ultimately become sperm mother cells or spermatogonia. Through a growth phase the speramtogonia converted into primary spermatocytes. These are diploid cells. They undergo meiotic cell division. Initially the I Meiosis results in the formation of secondary spermatocytes. Through II Meiosis they form spermatids. The spermatids are haploid in nature. Immediately after their formation, extensive morphological differentiation of spermatids occurs without further cell division to convert them into spermatozoa. By a process of spermiogenesis or spermioteliosis, they get differentiated into specialized cells called spermatozoa.

13.2.2 Oogenesis

The process involved in the development of a mature ovum is called oogenesis. A similar process happens inside the female gonad, namely the ovary for the production of Ova. This process that happens in the primordial germ cell of the ovary passes through stages of primary oogonia, primary oocyte and secondary oocyte. Majority of oogonia continue to divide, some enter into the prophase of the first meiotic division and are called primary oocytes. At birth, there is no more mitotic division and all the oogonia are replaced by primary oocytes. The primary oocytes do not finish first meiotic division until puberty is reached. Primary oocyte under go first meiotic division giving rise to secondary oocyte and one polar body.

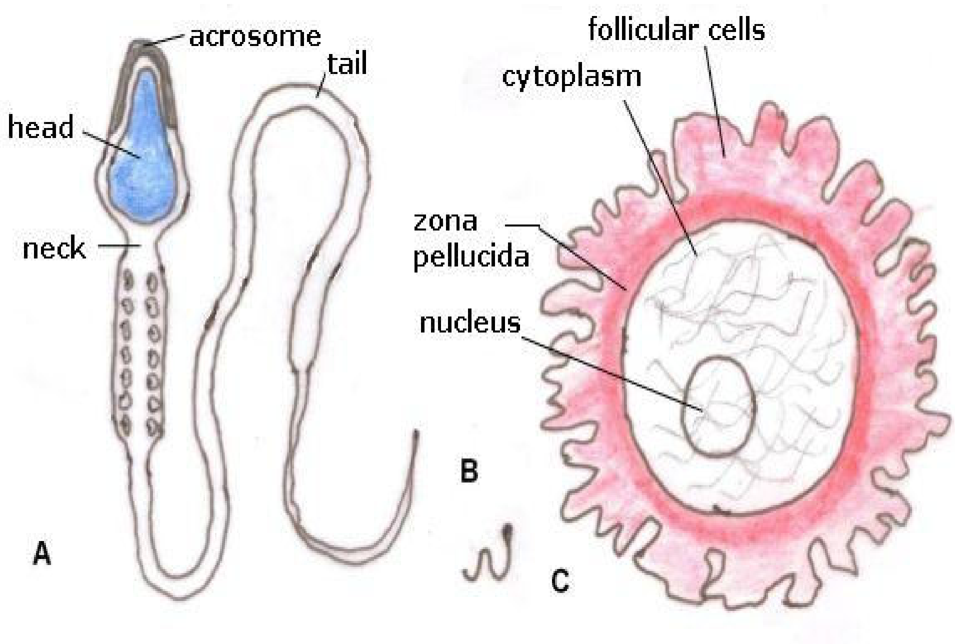


Maturation of the oocytes: These stages are conducted by meiotic cell divisions. Before onset of meiotic division, the primary oocytes double its

DNA by replication. Thus the final product, namely the ovum is a haploid female reproductive cell. The first stage of maturation occurs just prior to ovulation and final at after fertilization.

13.2.3 Sperm structure

Each sperm consists of a haploid nucleus, a propulsion system to move the nucleus and a sac of enzymes that enable the nucleus to enter the egg. Most of the sperm's cytoplasm is eliminated during maturation, leaving only certain organelles that are modified for spermatic function. The acrosome is the tip of the sperm head. The sperm head contains a haploid nucleus and an acrosome. The acrosome is derived from the golgi apperatus. The neck of sperm contains the mitochondria and the centriole which generates the microtubules of the flagellum. For flagellar motion, energy is derived from mitochondrial ATP and a dynein ATPase in the flagellum.



During the course of sperm maturation, the haploid nucleus becomes very streamlined, and its DNA becomes tightly compressed. In front of this compressed haploid nucleus lies the acrosomal vesicle, or acrosome, which contains enzymes that digest proteins and complex sugars; thus, it can be considered a modified secretory vesicle. These stored enzymes are used to lyse the outer coverings of the egg. In many species, such as sea urchins, a region of globular actin molecules lies between the nucleus and the acrosomal vesicle. These proteins are used to extend a fingerlike acrosomal process from the sperm during the early stages of fertilization. In most species, however, each sperm is able to travel long distances by whipping its flagellum. Flagella are complex structures. The major motor portion of the flagellum is called the axoneme. It is formed by microtubules emanating from the centriole at the base of the sperm nucleus. After being expelled into the lumen of the seminiferous tubules, the sperm are stored in the epididymis, where they acquire the ability to move. Motility is achieved through changes in the ATP-generating system (possibly through modification of dynein) as well as changes in the plasma membrane that make it more fluid. The sperm released during ejaculation are able to move, yet they do not yet have the capacity to bind to and fertilize an egg. These final stages of sperm maturation (called capacitation) do not occur until the sperm has been inside the female reproductive tract for a certain period of time.

13.2.4 Egg structure

The egg contains a haploid nucleus and an enlarged cytoplasm with ribosomes, mRNAs, Protective chemicals, nutritive proteins (yolk proteins), Morphogenetic factors (Molecules that direct the differentiation of cells into certain cell types are present in the egg) and cortical granules just beneath the eggs plasma memebrane. Enclosing the cytoplasm is the egg plasma membrane. This membrane regulates the flow of certain ions during fertilization and capable of fusing with the sperm plasma membrane. Surrounding the egg plasma membrane is an extracellular layer used in sperm recognition. In most animals, this layer is the vitelline envelop and it is the much thicker Zona pellucida in mammals. Generally, egg secretes diffusible molecules that attract and activate the sperm.

Vitelline envelope: Outside the plasma membrane is the vitelline envelope, which forms a fibrous mat around the egg. This envelope contains at least eight different glycoproteins and is often involved in sperm-egg recognition. The vitelline envelope is essential for the species-specific binding of sperm.

Zona pellucida In mammals, the vitelline envelope is a separate and thick extracellular matrix called the zona pellucida. The mammalian egg is also surrounded by a layer of cells called the cumulus, which is made up of the ovarian follicular cells that were nurturing the egg at the time of its release from the ovary. The innermost layer of cumulus cells, immediately adjacent to the zona pellucida, is called the corona radiata. Lying immediately beneath the plasma membrane of the egg is a thin shell (about 5 μm) of gel-like cytoplasm called the cortex. The cytoplasm in this region is stiffer than the internal cytoplasm and contains high concentrations of globular actin molecules. During fertilization, these actin molecules polymerize to form long cables of actin known as microfilaments. Microfilaments are necessary for cell division and they also are used to extend the egg surface into small projections called microvilli, which may aid sperm entry into the cell. Also within the cortex are the cortical granules. These membrane-bound structures, are Golgi-derived organelles containing proteolytic enzymes. Moreover, in addition to digestive enzymes, the cortical granules contain mucopolysaccharides, adhesive glycoproteins, and hyalin protein. The enzymes and mucopolysaccharides are active in preventing other sperm from entering the egg after the first sperm has entered and the hyalin and adhesive glycoproteins surround the early embryo and provide support for the cleavage-stage blastomeres. Many types of eggs also have an egg jelly outside the vitelline envelope. This glycoprotein meshwork can have numerous functions, but most commonly is used either to attract or to activate sperm.

13.3 Fertilization

The main function of fertilization is to combine the haploid sets of chromosomes from two individuals into a single diploid cell, the zygote. The other functions are to transmit genes from parent to offspring to ensure genetic variation and adaptability in the reproduction and activation of the egg. Egg activation blocks entry of additional sperm, stimulates the final meiotic division and triggers the onset of embryonic development. Fertilization includes in two separate activities.

Sex (combining of genes of two parents)

Reproduction (creation of a new organism)

In short, during the process of fertilization the sperm and ovum of the same species approach and come in contact with each other. The entry of sperm initiates further changes in the egg. The haploid nuclei of the sperm and ovum fuse, resulting in the formation of a diploid zygote nucleus. This process of nuclear fusion is known as syn-gamy or amphimixis. In some species (e.g., sea urchins), the nucleus is already haploid at the time of fertilization. In other species (including many worms and most mammals), the egg nucleus is still diploid and before sperm entering, the meiotic divisions should be completed.

Fertilization accomplishes in 4 steps.

1 **Contact and recognition between sperm and egg: This ensures that the sperm and egg are of same species.**

1. **Regulation of sperm entry into the egg:- ensure that only one sperm can fertilize the egg.**
2. **Fusion of genetic material from the two gametes**
3. **Activation of egg metabolism to start development**

11.3.1 Contact and recognition between sperm and egg

This ensures that the sperm and egg are of same species. In sea urchins and several other species, recognition between sperm and egg involves molecules on the acrosomal process. Species-specific sperm attraction has been documented in numerous species, including cnidarians, molluscs, echinoderms, and urochordates. In many species, sperm are attracted toward eggs of their species by chemotaxis, that is, by following a gradient of a chemical secreted by the egg.

However, after the completion of second meiotic division, the eggs are ready to be fertilized, the sperm migrated toward them. Thus, these oocytes control not only the type of sperm they attract, but also the time at which they attract them. The mechanisms of chemotaxis differ among species. One chemotactic molecule, a 14-amino acid peptide called resact, has been isolated from the egg jelly of the sea urchin. Resact acts as a sperm-activating peptide. The sperm receptor for resact is a transmembrane protein, and when it binds resact on the extracellular side, a conformational change on the cytoplasmic side activates the receptor's enzymatic activity. This activates the mitochondrial ATP-generating apparatus as well as the dynein ATPase that stimulates flagellar movement in the sperm.

Acrosomal Reaction :- A second interaction between sperm and egg is the acrosomal reaction. The acrosomal reaction is a change in the sperm that is common to many animals. Its function is best understood in the sea urchin. The acrosomal reaction in sea urchins is initiated by contact of the sperm with the egg jelly. After making its way through the jelly coat, the sperm makes contact with the vitelline envelope. Species-specific bindin receptors on the vitelline envelope are only able to recognize bindin molecules from the same species. This "lock and key" mechanism ensures that eggs are fertilized only by sperm of the same species. Contact with egg jelly causes the exocytosis of the sperm's acrosomal vesicle and the release of proteolytic enzymes that can digest a path through the jelly coat to the egg surface .

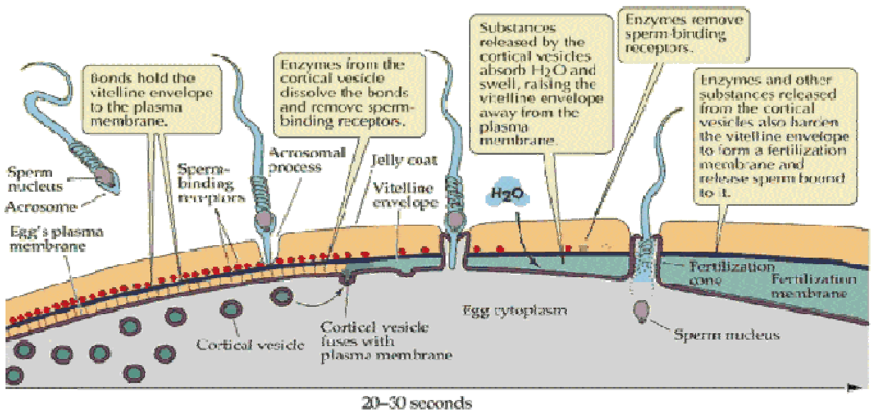
(1) Receptor proteins in the sperm plasma membrane contact the sea urchin jelly coat/vitelline layer. This contact causes the acrosomal membrane to

dissolve, releasing acrosomal enzymes. Globular actin polymerizes to extend the acrosomal process. Bindin on the process is recognised by a protein complex on egg surface. In mammals, acrosomal reaction is initiated on the zona pellucida and capacitation in female reproductive tract is essential before fertilization. In mouse , this binding is mediated by zona protein 3 (ZP3).

(2) In the egg, Na+ channels open in the plasma membrane (below the jelly coat/vitelline layer.) Normally, Na+ concentration is higher outside the cell than inside. So Na+ ions flow down their gradient into the egg and the plasma membrane depolarizes (positive charges neutralize the more negative charge inside the egg cytoplasm.) This depolarization causes the FAST BLOCK TO POLYSPERMY.

(3) The depolarization (neutralization of charge difference) causes voltage-sensitive Ca2+ channels to open in the egg endoplasmic reticulum (ER). (4) Digestive enzymes from the acrosomal vesicle (green) digest the jelly coat and vitelline membrane. Ca2+ also activates a Na+:H+ ion exchanger, which pumps H+ out of the cell, increasing intracellular pH. This pH change causes the polymerization of actin subunits into microfilament cables that thrust acrosomal processes toward the egg plasma membrane. Bindin released from the acrosomal vesicle.

(5) The increase in intracellular calcium causes water to enter the cell, increasing hydrostatic pressure. This aids in the extension of the acrosomal process. At last the acrosome fuses with the egg's plasma membrane (BENEATH the vitelline layer). The sperm head now has access



to the cytoplasm. In most marine invertebrates, the acrosomal reaction has two components: the fusion of the acrosomal vesicle with the sperm plasma membrane (an exocytosis that results in the release of the contents of the acrosomal vesicle) and the extension of the acrosomal process.

13.3.2 Regulation of sperm entry into the egg

The Ca2+ moves in a wave across the cell. This Ca++ results in the fusion of cortical vesicles with the egg plasma membrane, releasing their contents into the space surrounding the egg, called the perivitelline space. This raises the vitelline membrane, and inactivates bindin receptors on the vitelline membrane. Thus, any additional sperm are released from the vitelline membrane and no more bind. This is known as the slow block to polyspermy.

13.3.3 Fusion of genetic material from the two gametes

The sperm head now enters the cytoplasm, where it forms a male pronucleus. The pronucleus fuses with the egg nucleus, regenerating 2N chromosomes. Mitosis (first cleavage) then occurs. Fertilization is completes. In mammals, fertilin proteins in the sperm bind to integrins in the egg and allow the membranes to fuse.

Preventing polyspermy:

Although many sperm attach to the coats surrounding the egg, it is important that only one sperm fuses with the egg plasma membrane and delivers its nucleus into the egg. Two mechanisms are used by animals to ensure that only one sperm fertilizes a given egg are as given below.

Fast block theory: The fast block is electrical and is mediated by sodium ions.In marine invertebrates, including the sea urchin, a fast block to polyspermy occurs within a tenth of a second of fusion. The fast block to polyspermy involves the opening of Na+ channels in the egg plasma membrane. Na+ flows into the egg cell, depolarizing the membrane. This depolarization prevents additional sperm from fusing to the egg plasma membrane. The egg plasma membrane is restored to its normal -70mV potential within minutes of fusion as the Na+ channels close, other + ions flow out of the cell, and Na+ is pumped out. If depolarization is prevented, polyspermy occurs.

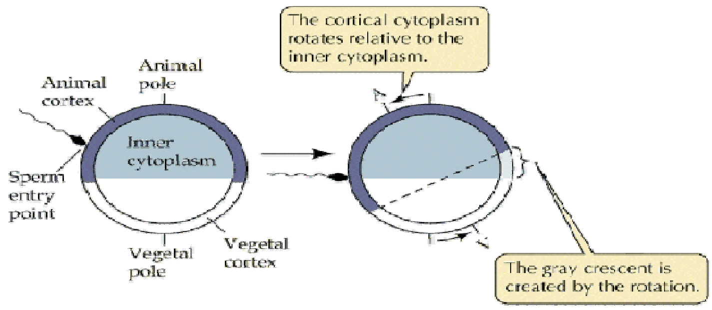
Slow block theory :- The slow block is physical and mediated by calcium ions. The slow block to polyspermy begins within 10 seconds of fusion of the sperm and egg plasma membranes. A compound called inositol triphosphate (IP3) causes the release of Ca++ from intracellular stores in the egg endoplasmic reticulum. Ca++ is first released at the site of sperm entry, and during the next minute, a wave of free Ca++ passes through the egg. This Ca^{++} results in the fusion of cortical vesicles with the egg plasma membrane, releasing their contents into the space surrounding the egg, called the perivitelline space. This raises the vitelline membrane, and inactivates bindin receptors on the vitelline membrane. Thus, any additional sperm are released from the vitelline membrane and no more bind. In vitro fertilization, the rate of polyspermy is as high as 10%.

13.3.4 Activation of egg metabolism to start development

Ca++ releases at fertilization results in an increase in metabolic activity within the egg, apparently due to an increase in the intracellular pH of the egg. Diacyl gycerol (DAG) causes protein phosphorylation cascades to be initiated, with one result being the phosphorylation and activation of a plasma membrane Na+:H+ ion exchanger. Na+ is pumped into the cell, H+ is pumped out of the cell, and the pH inside the cell increases. Sperm themselves are NOT required for egg activation - injection of Ca++ can artificially induce egg activation in many species.

Cortical rotation:-Positional information is already contained within many eggs, with the exception of mammals. Egg polarity is due to the asymmetric distribution of cytoplasmic molecules, including mRNAs, proteins, and yolk, and is roughly oriented along the anterior/posterior axis in most animals.

In Frogs:- A rearrangment of the egg cytoplasm is induced by fertilization, and this rearrangment (called cortical rotation) results in the establishment of the dorsal/ventral axis. During cortical rotation, the plasma membrane and cortex (cytoplasmic region just below the plasma membrane) rotate relative to the inner cytoplasm. The pigmentation of frog eggs makes it possible to observe this process visually, and results in a gray area, called the gray crescent.

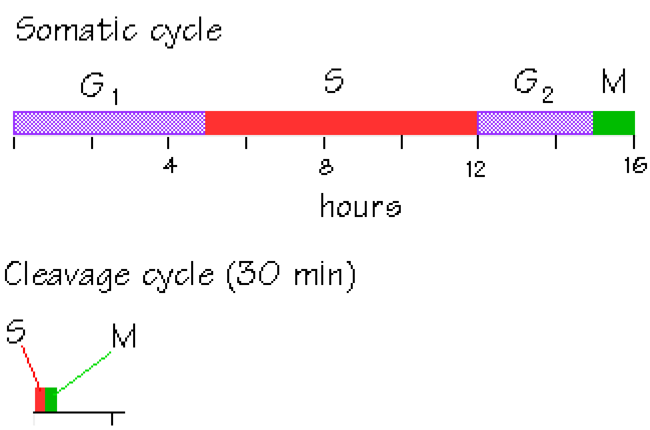


Once an egg is fertilized by a sperm, a zygote is formed. Fertilization provides the diploid nature to the cell. Thus all the somatic cells of the embryo will remain diploid. Further the process of fertilization triggers or initiates the initial stages of embryogenesis. The zygote divides into multiple cells in a process known as cleavage, triggering the beginning of embryonic differentiation.

13.4 Cleavage

Cleavage is a series of rapid cell divisions without cell growth or gene expression which occurs in early embryogenesis. Cleavage ends with the formation of the blastula. During cleavage, most cells do not grow. Rather, the volume of the oocyte is cleaved into numerous cells. The increase in intracellular free calcium ions activate DNA and protein synthesis and also activate the process for cell division.

Mechanism of cleavage differs among species and depends upon on the stage at which fertilization occurs. The major exceptions to this rule are mammals. However, rhythm of cell divisions is regulated by the synthesis and degradation of a protein called cyclin. Cyclin keeps cell in metaphase, and break down of cyclin enables the cell to return to interphase. Cyclin synthesis promotes the formation of MPF, and MPF promotes mitosis. Degradation of cyclin brings the cell back to the S phase. The G phases are added at the midblastula transition. Cleaving cells have a modified cell cycle, in which the two gap phases, G1 and G2, are completely omitted. The cells cycle rapidly between M and S phases. The cells derived are blastomeres and compact mass are called morula.



The processes of karyokinesis (mitosis) and cytokinesis work together to results in cleavage. The mitotic apparatus is made up of a central spindle and polar asters made up of polymers of tubulin protein called microtubules. The asters are nucleated by centrosomes and the centrosomes are organized by centrioles brought into the egg by the sperm as basal bodies. Cytokinesis is mediated by the contractile ring made up of polymers of actin protein called microfilaments. Karyokinesis and cytokinesis are independent. The end of cleavage coincides with the beginning of zygotic transcription. This point is referred to as the midblastula transition and appears to be controlled by the nuclear:cytoplasmic ratio.

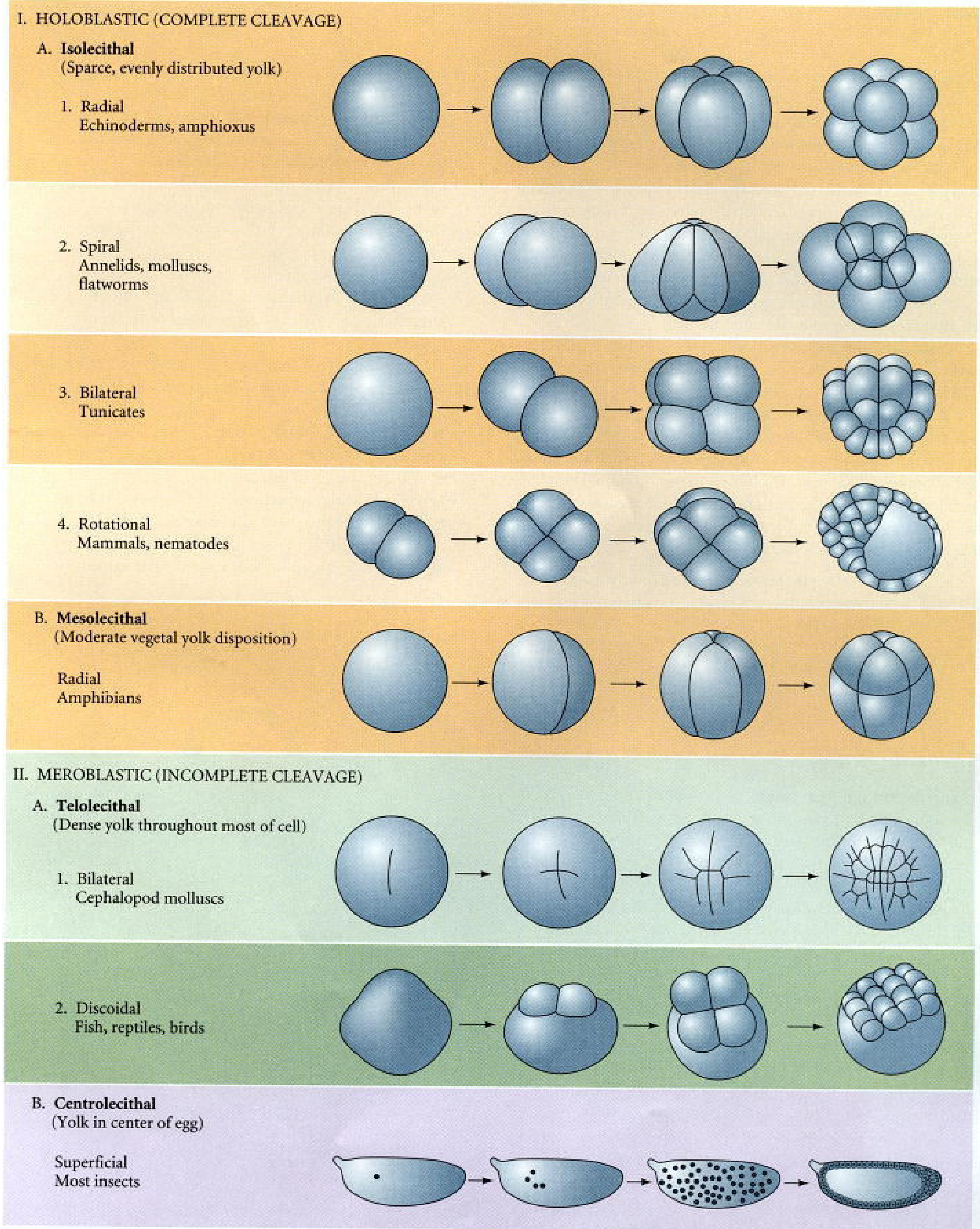
13.4.1 Types of cleavage

(1) **Determinate;-**Determinate cleavage (also called mosaic cleavage) is in most protostomes. Each blastomere produced by early embryonic cleavage does not have the capacity to develop into a complete embryo.

(2) **Indeterminate;-** When the original cell in a deuterostome embryo divides, the resulting each one can individually develop into a whole organism.

The pattern of cleavage is influenced by the amount of yolk in the egg. The pole of the egg which has highest concentration of yolk is referred vegetal pole while the opposite is referred to as the animal pole. Depending on the amount of yolk in the egg, the cleavage can be Summarized as below.

(3) **Holoblastic (total or entire cleavage:-** In eggs with less yolk, cleavages are equal, and the resulting blastomeres are of similar size. In the absence of a large concentration of yolk, four major cleavage types can be observed in isolecithal cells (cells with a small even distribution of yolk) or in mesolecithal cells (moderate amount of yolk in a gradient) - bilateral holoblastic, radial holoblastic, rotational holoblastic, and spiral holoblastic, cleavage. In invertebrates, cleavage is holoblastic. In the sea urchin, cleavage is radial; in the snail, spiral; in the tunicate, bilateral; and in the nematode, rotational



I. HOLOBLASTIC (COMPLETE CLEAVAGE)
A. Isolecithal
(Sparce, evenly distributed yolk)
1. Radial
Echinoderms, amphioxus
2. Spiral
Annelids, molluscs, flatworms
3. Bilateral
Tunicates
4. Rotational
Mammals, nematodes
B. Mesolecithal
(Moderate vegetal yolk disposition)
Radial
Amphibians
II. MEROBLASTIC (INCOMPLETE CLEAVAGE)
A. Telolecithal
(Dense yolk throughout most of cell)
1. Bilateral
Cephalopod molluscs
2. Discoidal
Fish, reptiles, birds
B. Centrolecithal
(Yolk in center of egg)
Superficial
Most insects

I. Holoblastic (complete) cleavage	II. Meroblastic (incomplete) cleavage
A. Isolecithal (sparse, evenly distributed yolk) • Radial cleavage (echinoderms, hemichordates, amphioxus) • Spiral cleavage (annelids, most mollusks, flatworms) • Bilateral cleavage (tunicates) • Rotational cleavage (placental mammals, nematodes, marsupials [?]) B. Mesolecithal (moderate vegetal yolk disposition) • Displaced radial cleavage (amphibians, some fish [the lampreys, gars and bowfins)	A. Telolecithal (dense yolk throughout most of cell) • Bilateral cleavage (cephalopod molluscs) • Discoidal cleavage (some fish [the hagfishes, chondrichthyans and most teleosts], sauropsids [reptiles and birds], monotremes) B. Centrolecithal (yolk in center of egg) • Superficial cleavage (most insects)

Radial cleavage:- Radial cleavage is characteristic of the deuterostomes, which include some vertebrates and echinoderms, in which the spindle axes are parallel or at right angles to the polar axis of the oocyte. The simplest pattern is radial cleavage, in which successful division planes are at 90 degree angles relative to each other. These results in the blastomeres aligned directly over or to the side of one another. These holoblastic cleavage planes pass all the way through isolecithal zygotes during the process of cytokinesis. Coeloblastula is the next stage of development for eggs that undergo these radial cleavaging. In holoblastic eggs the first cleavage always occurs along the vegetal-animal axis of the egg, the second cleavage is perpendicular to the first. From here the spatial arrangement of blastomeres can follow various patterns, due to different planes of cleavage, in various organisms.

Bilateral cleavage:-The first cleavage results in bisection of the zygote into left and right halves. The following cleavage planes are centered on this axis and result in the two halves being mirror images of one another. In bilateral holoblastic cleavage, the divisions of the blastomeres are complete and separate; compared with bilateral meroblastic cleavage, in which the blastomeres stay partially connected.

Rotational cleavage:-Mammals display rotational cleavage, and an isolecithal distribution of yolk (sparsely and evenly distributed). Because the cells have only a small amount of yolk, they require immediate implantation onto the uterine wall in order to receive nutrients. Rotational cleavage involves a normal first division along the meridional axis, giving rise to two daughter cells. The way in which this cleavage differs is that one of the daughter cells divides meridionally, whilst the other divides equatorially.

Spiral cleavage:- Most spiralians undergo equal spiral cleavage, although some undergo unequal cleavage. This group includes annelids, molluscs, and sipuncula. In this division planes are not at 90 degree angles, resulting in blastomeres that are NOT aligned directly over or beside one another. Spiral cleavage can vary between species, but generally the first two cell divisions result in four macromeres, also called blastomeres, (A, B, C, D) each representing one quadrant of the embryo. These first two cleavages are oriented in planes that occur at right angles parallel to the animal-vegetal axis of the zygote. In equal cleavage, the first two cell divisions produce four macromeres that are indistinguishable from one another. In unequal cleavage, the first two cell divisions are unequal producing four cells in which one cell is bigger than the other three. This larger cell is specified as the D macromere.Unlike equally cleaving spiralians, the D macromere is specified at the four-cell stage during unequal cleavage.

(4) Meroblastic (partial cleavage) :- In the presence of a large amount of yolk in the fertilized egg cell, the cell can undergo partial, or meroblastic, cleavage. Two major types of meroblastic cleavage are discoidal and superficial.

Discoidal cleavage:-If the yolk is localized, such as in frog eggs, then cleavages are unequal - the cells derived from the yolky region (the vegetal pole) are larger than those derived from the region without yolk (the animal pole). In the very yolky eggs of fish and birds, the cleavage furrow is slowed, or even blocked, by the presence of the yolk. Complete divisions are restricted to the least yolky region of the egg, and the embryo forms as a cap of cells sitting on top of the yolk. The embryo forms a disc of cells, called a blastodisc, on top of the yolk. Discoidal cleavage is commonly found in monotremes, birds, reptiles, and fish that have telolecithal egg cells (egg cells with the yolk concentrated at one end). **Superficial cleavage:-**In superficial cleavage, mitosis occurs but not cytokinesis, resulting in a polynuclear cell. With the yolk positioned in the center of the egg cell, the nuclei migrate to the periphery of the egg, and the plasma membrane grows inward, partitioning the nuclei into individual cells. Superficial cleavage occurs in arthropods that have centrolecithal egg cells (egg cells with the yolk located in the center of the cell).

13.5 Blastula

A blastula is an embryonic structure derived from cleavage in an early embryo composed of blastomeres and the blastocoel. If the blastula lacks a blastocoel, it is a stereo blastula. A mammalian blastula is called a blastocyst and the invagination where gastrulation begins is the blastopore.

In placental mammals :-Mammals have a slow rate of division that is between 12 and 24 hours. These cellular divisions are asynchronous. Zygotic transcription starts at the two-, four-, or eight-cell stage. Cleavage is holoblastic and rotational. At the eight-cell stage, the embryo goes through some changes. Most of the blastomeres in this stage become polarized and develop tight junctions with the other blastomeres. This process leads to the development of two different populations of cells: Polar cells on the outside and apolar cells on the inside. The outer cells, called the trophoblast cells, pump sodium in from the outside, which automatically brings water in with it to the basal (inner) surface to form a blastocoel cavity in a process called compaction. The embryo is now called a blastocyst. The trophoblast cells will eventually give rise to the embryonic contribution to the placenta called the chorion. The inner cells are pushed to one side of the cavity (because the embryo isn't getting any bigger) to form the inner cell mass (ICM) and will give rise to the embryo and some extraembryonic membranes. At this stage, the embryo is called a blastocyst. The mammalian zygote gives rise to both the embryo and extraembryonic tissues, such as the placenta. Changes in cell behavior and cell cleavage patterns during early embrogenesis results in a 32-cell blastocyst consisting of the inner cell mass, which will form the embryo, and the trophoblast, which will form extraembryonic tissues.

Early Invertebrate Development Embryonic differentiation is the process of development during which embryonic cells specialize and diverse tissue structures arise. Differentiation of cells during embryogenesis is the key to cell, tissue, organ, and organism identity.

13.6 Gastrulation

The process of formation of gastrula is called gastrulation. In the beginning, the gastrula is a two layered stage with a cavity called archenteron. During the process of gastrulation there are mass movement of sub cells called formative movements. This archenteron opens to the exterior by means of an opening called blastopore. As a result of gastrulation, three primary layers are formed. These are the ectoderm, the endoderm and the mesoderm. First to develop are the ectoderm and the endoderm and eventually the mesoderm is also formed. Cells in these three layers will give rise to different parts of the organism. **Ectoderm** differentiates into the nervous system and skin. **Endoderm** eventually becomes the gut. **Mesoderm** develops into muscle, the skeletal system, some organs, and connective tissue.

The process of gastrulation takes place at the following stages.

Invagination :-The infolding of a region of cells, much like the indenting of a soft rubber ball when it is poked. A small depression is formed in the region occupied by the grey crescent area. As the gastrocoel increases in size the blastocoel gets reduced. Ultimately only a slit like semicircular cavity indicates the remnants of the blastocoel. The blastopore meanwhile becomes expanded and becomes ring shaped.

Involution:- The inward movement of an expanding outer layer so that it spreads over the internal surface of the remaining external cells. The endoderm is the first to roll inside. The cells of the notochord and mesoderm which were formed outside now migrate over the lip of blastopore and become internal and arrange themselves on the roof, sides and the floor of the archenteron. The notochord cells are found on the roof along the midline. While the endoderm forms the anterior, lateral and ventral walls, the mesoderm forms wing like extensions in the archenter.

Ingression:- The migration of individual cells from the surface layer into the interior of the embryo.

Delamination:- The splitting of one cellular sheet into two more or less parallel sheets.

Epiboly:- The movement of epithelial sheets (usually of ectodermal cells) that spread as a unit, rather than individually, to enclose the deeper layers of the embryo. In the late blastula, the anterior half consists of micromeres which constitute the ectoderm while the posterior megameres constitute the endoderm. The germ ring forms the mesoderm. In other words the pigmented micromeres (animal half) grow over the megameres (vegetative half). The reason for overgrowth is the rapid rate of division of micromeres.

Closure of the blastopore:-The archenteron at its beginning is marked by a groove. The anterior margin of this groove is called dorsal lip of the blastopore. This groove also extends laterally to form the lateral and ventral lips. At this stage, the blastopore is completely ring like, surrounding the endoderm. The circular area of the endoderm is represented by a mass of cells called the yolk plug. The margins of the lips of the blastopore contract making the opening very small. At this stage the yolk plug has an oval outline and eventually becomes a small speck and is completely covered over by the ectoderm cells.

Rotation:- At the end of gastrulation the yolk filled cells get rearranged. This rearrangement shifts the centre of gravity of the gastrula and results in a rotation of eighty to ninty degrees. The blastopore moves backwards and is finally located slightly above its original location at the beginning of the gastrula.

Convergence:-During this process there are two kinds of cell movements. First, there is shifting of the cells of the notochord and mesoderm towards the dorsal lips. Secondly, there is a dorsal convergence of notochord and mesodermal cells towards the middorsal area of the blastopore.

In amniotes, gastrulation occurs in the following sequence: (1) the embryo becomes asymmetric; (2) the primitive streak forms; (3) cells from the epiblast at the primitive streak undergo an epithelial to mesenchymal transition and ingress at the primitive streak to form the germ layers.

Loss of symmetry:

In preparation for gastrulation, the embryo must become asymmetric along both the proximal-distal axis and the anterior-posterior axis. The proximal-distal axis is formed when the cells of the embryo form the "egg cylinder," which consists of the extraembryonic tissues, which give rise to structures like the placenta, at the proximal end and the epiblast at the distal end. Many signaling pathways contribute to this reorganization, including BMP, FGF, nodal, and Wnt. Visceral endoderm surrounds the epiblast. The distal visceral endoderm (DVE) migrates to the anterior portion of the embryo, forming the "anterior visceral endoderm" (AVE). This breaks anterior-posterior symmetry and is regulated by nodal signaling. Epithelial to Mesenchmyal Cell Transition – loss of cell adhesion leads to constriction and extrusion of newly mesenchymal cell.

Formation of the primitive streak:- The primitive streak is formed at the beginning of gastrulation and is found at the junction between the extraembryonic tissue and the epiblast on the posterior side of the embryo and the site of ingression.../../../hp/Desktop/Gastrulation - Wikipedia, the free encyclopedia.html - cite_note-Tam-9 Formation of the primitive streak is reliant upon nodal signaling in the Koller's sickle within the cells contributing to the primitive streak and BMP4 signaling from the extraembryonic tissue. Furthermore, Cer1 and Lefty1 restrict the primitive streak to the appropriate location by antagonizing nodal signalling. The region defined as the primitive streak continues to grow towards the distal tip.

During the early stages of development, the primitive streak is the structure that will establish bilateral symmetry, determine the site of gastrulation and initiate germ layer formation. To form the streak, reptiles, birds and mammals arrange mesenchymal cells along the prospective midline, establishing the first embryonic axis, as well as the place where cells will ingress and migrate during the process of gastrulation and germ layer formation. The primitive streak extends through this midline and creates the antero-posterior body axis, becoming the first symmetry-breaking event in the embryo, and marks the beginning of gastrulation. This process involves the ingression of mesoderm and endoderm progenitors and their migration to their ultimate position, where they will differentiate into the three germ layers. The localization of the cell adhesion and signaling molecule beta-catenin is critical to the proper formation of the organizer region that is responsible for initiating gastrulation.

Epithelial to mesenchymal transition and ingression

In order for the cells to move from the epithelium of the epiblast through the primitive streak to form a new layer, the cells must undergo an epithelial to mesenchymal transition (EMT) to lose their epithelial characteristics, such as cell-cell adhesion. FGF signaling is necessary for proper EMT. FGFR1 is needed for the up regulation of Snail1, which down regulates E-cadherin, causing a loss of cell adhesion. Following the EMT, the cells ingress through the primitive streak and spread out to form a new layer of cells or join existing layers. FGF8 is implicated in the process of this dispersal from the primitive streak.

In sea urchins, cell fates are determined by signaling. The micromeres constitute a major signaling center. β-catenin is important for the inducing capacity of the micromeres. Differential cell adhesion is important in regulating sea urchin gastrulation. The micromeres delaminate first from the vegetal plate. They form the primary mesenchyme which becomes the skeletal rods of the pluteus larva. The vegetal plate invaginates to form the endodermal archenteron, with a tip of secondary mesenchyme cells. The archenteron elongates by convergent extension and is guided to the future mouth region by the secondary mesenchyme.

Snails exhibit spiral cleavage and form stereoblastulae, having no blastocoels. The direction of the spiral cleavage is regulated by a factor encoded by the mother and placed into the oocyte. Spiral cleavage can be modified by evolution, and adaptations of spiral cleavage have allowed some molluscs to survive in otherwise harsh conditions.The polar lobe of certain molluscs contains the determinants for mesoderm and endoderm. These will enter the D blastomere.

The tunicate fate map is identical on its right and left sides. The yellow cytoplasm contains muscle-forming determinants; these act autonomously. The nervous system of tunicates is formed conditionally, by interactions between blastomeres. The soil nematode Caenorhabditis elegans was chosen as a model organism because it has a small number of cells, a small genome, is easily bred and maintained, has a short lifespan, can be genetically manipulated, and has a cuticle through which one can see cell movements. In the early divisions of the C. elegans zygote, one daughter cell becomes a founder cell (producing differentiated descendants) and the other becomes a stem cell (producing other founder cells and the germ line).Blastomere identity in C. elegans is regulated by both autonomous and conditional specification.

Body axes:- In some, such as the sea urchin and tunicate, the axes are established at fertilization through determinants in the egg cytoplasm. In such as the nematode and snail, the axes are established by cell interactions later in development. Three axes are the foundations of the body: **Anterior-posterior axis** (head to tail or mouth to anus), **Dorsal-ventral axis** (back to belly), **Right-left axis** (between the two lateral sides of the body).

13.7 Summary

How sperm and egg formation take place in male and female gonads. How fertilization processes take place and what are two typa method to prevent the polyspermy. Significance of fertilization. Types of cleavage in embryo; How the type of egg influences clevage fate of blastopore (deuterostom, protostome) and fate of blastomere(determinate, Indeterminate) in embryo. Blastula formation and gastrulation process completed. How three germ layer are formed and what organ they form

This is the most essential lesson for a student before you start reading about development of organism Let's start from very basic, all animals have a male and female sex organism . Whether the animals are made up of two germ layers (diploblastic) or three (triploblastic). How this structure develop from zygote. During development of embryo, what does blastopore form mouth or anus? Accordingly animals are classified under two categories-deuterostom and protostome.There are embryos in which fate of blastopore is predetermined ie what these cells will make as embryo grows and in some it's not determined.

13.8 Glossary

- **Gametogenesis** - gamete production (i.e. Meiosis.
- **Fertilization** - union of sperm & egg cell --> 2n zygote
- **Cleavage** - rapid succession of cell divisions forms hollow ball of cells called Blastula embryo
- **Gastrulation** - period of cell migrations as Blastula embryo converted into a 3 layered stage called Gastrula embryo.
- **Organogenesis** - Organ Formation
- **Spiral cleavage**: Resulting daughter cells are not located exactly on top of one another; instead, they are located at a slight angle
- **Radial cleavage**: Resulting daughter cells are located exactly on top of one another
- **Protostome**: Blastopore of embryo forms mouth in adult
- **Deuterostom**: Blastopore of embryo form anus in adult
- **Determinate**: Blastomeres in embryo forms determined structures in embryo
- **Indeterminate**: Blastomeres in embryo are capable of forming any other structure in adults

13.9 Self-Learning Exercise

1 Define:

1. Clevage

2. Spermatogenesis
3. Organogenesis

2 Draw well labelled diagram of sperm

3 How polyspermy can be prevented?

4 Explain structure of ovum.

5 Explain various events of fertilization.

6 How many type of cleavage occurs? Give a well explained diagram of types of cleavage.

7 Explain blastula stages.

8 How germ layer are formed

Section -A (Very Short Answer Type):

1. formation of sperm is called ....

2. zygote is formed by the process of ....

3. is known as ....symmetry

4. Defineblastual

5. Deuterostom: Blastopore of embryo forms anus in adult T/F

6. polyspermy is seen when ....

7 Define gastrulation

Section -B (Short Answer Type) :

1. Name the three primary germ layers of a triploblastic animal.
2. Define the fast block theory?
3. Define structure of sperm? Give diagram.
4. Explain clevage; Give example.
5. What is polyspermy.
6. How does egg is formed?
7. Define germ layer?

Section -C (Long Answer Type)

1. Explain what is Gametogenesis
2. Write about germ layers and their derivatives
3. Describe fate of Blastopore, draw suitable diagrams.

4. What is cell surface molecules in sperm-egg recognition in animals?
5. With the help of diagrams explain cleavage.
6. How fertilization process acoomplished.

1.9 References

- Development Biology by Gilbert

Unit - 14

Morphogenesis and Organogenesis in Animals

Structure of the Unit

14.1 Objectives

This unit gives an account of morphogenesis and organogenesis in animals. It introduces the reader to axes and pattern formation and organogenesis in animals. By the end of this unit you will be able to describe the cells aggregation and differentiation in *Dictyostelium,* axes and pattern formation in *Drosophila*, amphibia and chick; Organogenesis – vulva formation in *Coenorhabditis elegans*; eye lens induction, limb development and regeneration in vertebrates; differentiation of neurons, post embryonic development - larva formation, metamorphosis; Homeobox concept in different phylogenetic groups.

14.2 Introduction

Morphogenesis is the biological process that causes an organism to develop its shape. It is one of three fundamental aspects of developmental biology along with the control of cell growth and cellular differentiation.The process controls the organized spatial distribution of cells during the embryonic development of an organism. Morphogenesis can take place also in a mature organism, incell culture or inside tumor cell masses. Morphogenesis also describes the development of unicellular life forms that do not have an embryonic stage in their life cycle, or describes the evolution of a body structure within a taxonomic group.

Morphogenetic responses may be induced in organisms by hormones, by environmental chemicals ranging from substances produced by other organisms to toxic chemicals orradionuclides released as pollutants, and other plants, or by mechanical stresses induced by spatial patterning of the cells.

In animal development, organogenesis is the process by which the ectoderm,endoderm, and mesoderm develop into the internal organs of the organism. Internal organs initiate development in humans within the 3rd to 8th weeks in utero. The germ layers in organogenesis differ by three processes: folds, splits, and condensation. Developing early during this stage in chordate animals are thenotochord, which induces the formation of the neural plate, and ultimately the neural tube. Vertebrate animals all differentiate from the gastrula the same way. Vertebrates develop a neural crest that differentiates into many structures, including some bones, muscles, and components of the peripheral nervous system. Thecoelom of the body forms from a split of the mesoderm along the somite axis.

15.3 Cell aggregation and differentiation in *Dictyostelium*

The life cycle of dictyostelium:

Another type of multicellular organization derived from unicellular organisms is found in D*ictyostelium discoideum*.In its asexual cycle, solitary haploid amoebae (called myxamoebae or “social amoebae” to distinguish them from amoeba species that always remain solitary) live on decaying logs, eating bacteria and reproducing by binary fission. When they have exhausted their food supply, tens of thousands of these myxamoebae join together to form moving streams of cells that converge at a central point. Here they pile atop one another to produce a conical mound called a tight aggregate. Subsequently, a tip arises at the top of this mound, and the tight aggregates bends over to produce the migrating slug (with the tip at the front). The slug (often given the more dignified title of pseudoplasmodium or grex) is usually 2-4 mm long and is encased in a slimy sheath. The grex begins to migrate (if the environment is dark and moist) with its anterior tip slightly raised. When it reaches an illuminated area, migration ceases, and the grex differentiates into a fruiting body composed of spore cells and a stalk. The anterior cells, representing 15-20% ofthe entire cellular population, from the tubed stalk. This process begins as some of the central anterior cells, the prestalk cells, begins secreting an extracellular coat and extending a tube through the grex. As the prestalk cells differentiate, they form vacuoles and enlarge, lifting up the mass of prespore cells that had made up the posterior four-fifths of the grex. The stalk cells die, but the prespore cells, elevated above the stalk, become spore cells. These spore cells disperse, each one becoming a new myxamoeba.

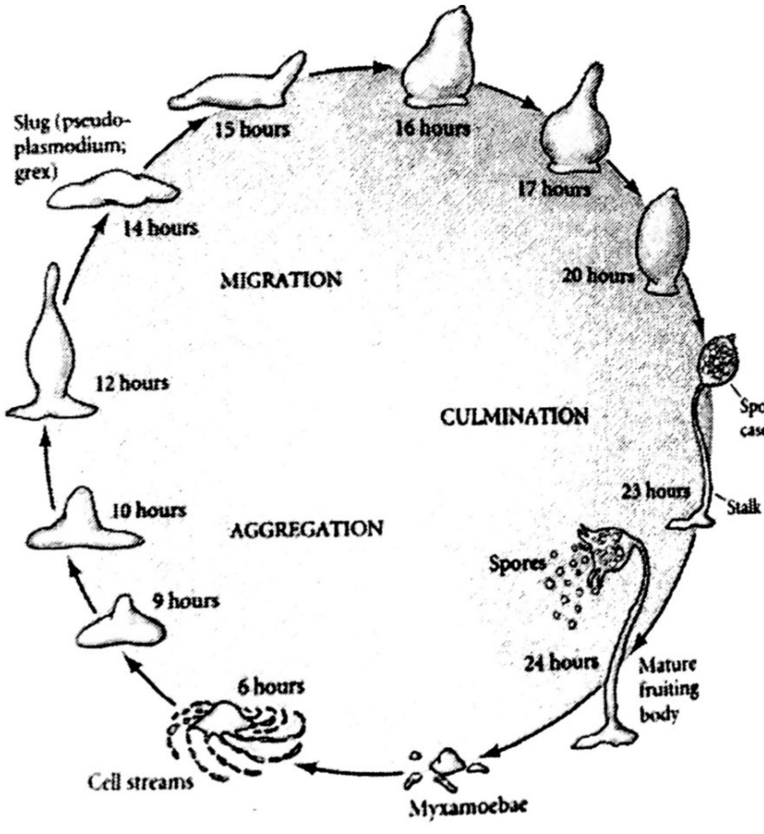


Fig. Life history of *Dictyostelium discoideum*

In addition to this asexual cycle, there is a possibility for sex in Dictyostelium. Two myxamoebae can fuse to create a giant cell, which digests all the other cells of the aggregate. When it has eaten all its neighbors, it encysts itself in a thick wall and undergoes meiotic and mitotic divisions; eventually, new myxamoebae are liberated.

Dictyostelum has been a wonderful experimental organism for developmental biologist because initially identical cells are differentiated into one of two alternative cell types, spore and stalk. The aggregation of thousands of myxamoebae into a single organism is an incredible feat of organization that invites experimentation to answer questions about the mechanisms involved.

Aggregation is initiated as each of the cells begins to synthesize cAMP. There are no dominant cells that begin the secretion or control the others. Rather, the sites of aggregation are determined by the distribution of myxamoebae. Neighbouring cells respond to cAMP in two ways: they initiate a movement toward the cAMP pulse, and they release cAMP of their own. After this, the cell is unresponsive to further cAMP pulses for several minutes. The result is a rotating spiral wave of cAMP that is propagated throughout the population of cells. As each wave arrives, the cells take another step toward the center.

The differentiation of individual myxamoebae into either stalk (somatic) to spore (reproductive) cells is a complex matter. Raper (1940) and Bonner (1957) demonstrated that the anterior cells normally become stalk, while the remaining, posterior cells are usually destined to form spores. However, surgically removing the anterior part of slug does not abolish its ability to form a stalk. Rather the cells that now find themselves at the anterior end (and which originally had been destined to produce spore) now form the stalk. Somehow a discussion is made so that whichever cells are anterior become stalk cells and whichever are posterior become spores. This ability of cells to change their developmental fates according to their location within the whole organisms and their by compensate for missing part is called regulation. We will see this phenomenon in many embryos including those of mammals.

Cell adhesion molecules in *Dictyostelium*

How do individual cells stick together to form a cohesive organism? This problem is the same one that embryonic cells face, and the solution that evolved in the protists is the same one used by embryos: developmentally regulated cell adhesion molecules.

While growing mitotically on bacteria, *Dictyostelium* cells do not adhere to one another. However, once cell division stops, the cells become increasingly adhesive, reaching a plateau of maximum cohesiveness around 8 hours after starvation. The initial cell-cell adhesion is mediated by a 24,000 Da (24 kDa) glycoprotein that is absent in myxamoebae but appears shortly after division ceases. This protein is synthesized from newly transcribed mRNA and becomes localized in the cells membranes of the myxamoebae. If myxamoebae are treated with antibiotics that bind to and mask this protein, they will not stick to one another, and all subsequent development ceases.

Once this initial aggregation has occurred, it is stabilized by second cell adhesion molecules. This 80-kDa glycoprotein is also synthesized during the aggregation phase. If it is defective or absent in the cells, small slugs will form, and their fruiting bodies will be only about one-third the normal size. Thus, the second cell adhesion system seems to be need for retaining a large enough number of cells to form large fruiting bodies in addition a third cell adhesion system is activated late in development while the slug is migrating.

This protein appears to be important in the movement of the prestalk cells to the apex of the mound. Thus, *Dictyostelium* has evolved three developmentally regulated systems of cell-cell adhesion that are necessary for the morphogenesis of individual cells into a coherent organism. Metazoan cells also use cell adhesion molecules to form the tissues and organs of the embryo.

Dictyostelium is a “part-time multicellular organism” that does not form many cell types, and the more complex multicellular organisms do not form by the aggregation of formerly independent cells. Nevertheless, many of the principles of development demonstrated by this “simple” organism also appear in embryo of more complex phyla. The ability of individual cells to ense a chemical gradient (as in the myxamoebae’s response to cAMP) is veru important for cell migration and morphogenesis during animal development. Moreover the role of cell surface protein in cell cohasiveness is seen throughout animal kingdom and differentiation inducing molecules are begning to be isolated in metazoan organisms.

Differentiation in *dictyostelium*

Differentiation into stalk cell or spore cell reflects another major phenomenon of embryogenesis: the cell's selection of a developmental pathway. Cells often select a particular developmental fate when alternatives are available. A particular cell in a vertebrate embryo, for instance, can become either an epidermal skin cell or a neuron. In *Dictyostelium*, we see a simple dichotomous decision, because only two cell types are possible. How is it that a given cell becomes a stalk cell or a spore cell? Although the details are not fully known, a cell's fate appears to be regulated by certain diffusible molecules. The two major candidates are differentiation inducing factor (DIF) and cAMP. DIF appears to be necessary for stalk cell differentiation. This factor, like the sex-inducing factor of Volvox, is effective at very low concentration (10-10M); and, like the Volvox protein, it appears to induce differentiation into a particular type of cell.

When added to isolated myxamoebae or even to prespore (posterior) cells, it causes them to form stalk cells. The symthesis of this low molecular weight lipid is genetically regulated, for there are mutant strains of *Dictyostelium* that form only spore precursors and no stalk cells. When DIF is added to these mutant cultures, stalk cells are able to differentiate, and new prestalk-specific mRNAs are seen in the cell cytoplasm. While the mechanisms by which DIF induces 20% of the grex cells to become stalk tissue are still controversial, DIF may act by releasing calcium ions from intracellular compartments within the cell.

Although DIF stimulates mtxamoebae to become pre-stalk cells, the differentiation of prespore cells is most likely controlled by the continuing pulses of cAMP. High concentrations of cAMP intiate the expression of pre-spore specific mRNAs in aggregated myxamoebae. Moreover, whan slugs are placed in a medium containing an enzyme that destroys extracellular cAMP, the prespore cells lose their differentiated characteristics.

The biochemistry of this reaction involves a receptor that binds cAMP. When this binding occurs, specific gene transcription take place, motility toward the source of the cAMP is initiated, and adenyl cyclase enzymes (which synthesize cAMP from ATP) are activated. The newly formed cAMP activates the cell's own receptors, as well as those of its neighbors.

The cells in the area remain insensitive to new waves of cAMP until the bound cAMP is removed from the receptors by another cell surface enzyme, phosphodiesterase.

The mathematics of such oscillation reactions predict that the diffusion of cAMP should initially be circular. However, as cAMP interacts with the cells that receive and propagate the signal, the cells that receive front part of the wave begin to migrate at a different rate than the cells behindthem. The result is the rotating spiral of cAMP and migration. Interestingly, the same mathematical formulas predict the behavior of certain chemical reactions and the formation of new stars in rotating spiral galaxies.

15.4 Axis and Pattern Formation in Drosophila, amphibia and chick

The Genetics of Pattern Formation in Drosophila:

One of the best-studied systems for the genetic control of pattern formation is the early embryonic development of *Drosophila melanogaster*. Geneticists have isolated a large number of mutations in fruit flies that influence all aspects of their development, and these mutations have been subjected to molecular analysis, providing much information about how genes control early development in *Drosophila*.

The Development of the fruit fly

An adult fruit fly possesses three basic body parts: head, thorax and abdomen. The thorax consists of three segments: the first thoracic segment carries a pair of legs; the second thoracic segment carries a pair of legs and a pair of wings: and the third thoracic segment carries a pair of legs and the halteres (rudiments of the second pair of wings found in most other insects). The abdomen contains nine segments.

When a *Drosophila* egg has been fertilized, its diploid nucleus immediately divides nine times without division of the cytoplasm, creating a single, multinucleate cell. These nuclei are scattered throughout the cytoplasm but later migrate toward the periphery of the embryo and divide several more around each nucleus, creating a layer of approximately 6000 cells at the outer surface of the embryo.

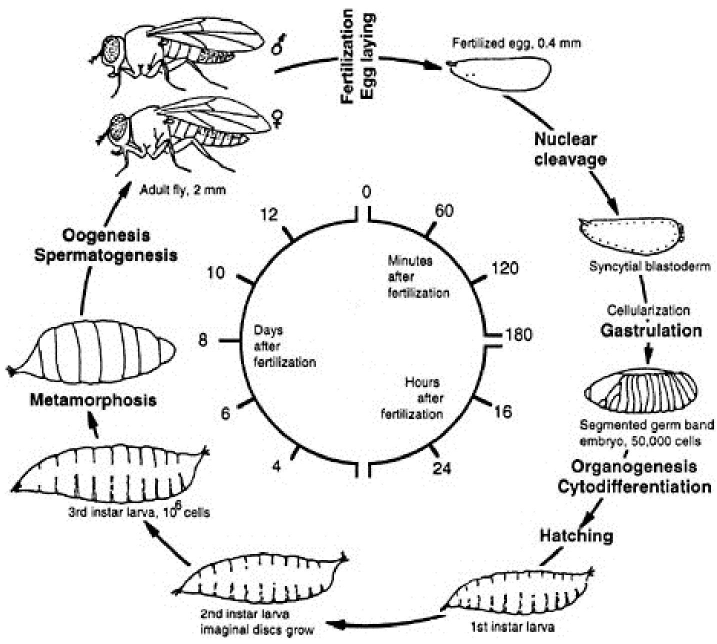


Fig. Life cycle of *Drosophila melanogaster*

Anterior posterior axis patterning in Drosophila

One of the best understood examples of pattern formation is the patterning along the future head to tail (antero-posterior) axis of the fruit fly *Drosophila melanogaster*. There are three fundamental types of genes that give way to the developmental structure of the fly: maternal effect genes, segmentation genes, and homeotic genes.

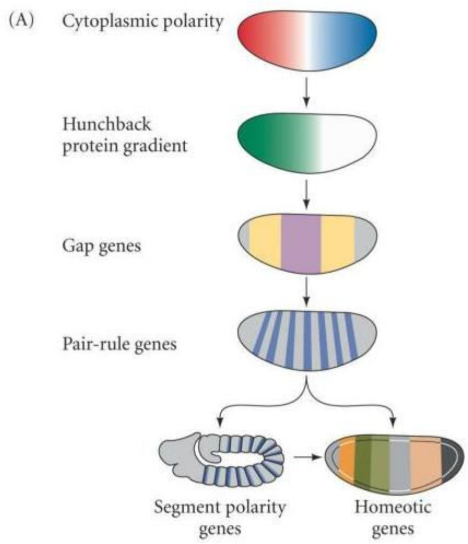


Fig. Generalized model of Drosophila anterior- posterior pattern formation. The pattern is established by maternal effect genes that form gradients and regions of morphogenetic proteins.

The development of *Drosophila* is particularly well studied, and it is representative of a major class of animals, the insects or insecta. Other multicellular organisms sometimes use similar mechanisms for axis formation, although the relative importance of signal transfer between the earliest cells of many developing organisms is greater than in the example described here.

Maternal effect genes

The building-blocks of anterior-posterior axis patterning in *Drosophila* are laid out during egg formation (oogenesis), well before the egg is fertilized and deposited. The maternal effect genes are responsible for the polarity of the egg and of the embryo. The developing egg (oocyte) is polarized by differentially localized mRNA molecules.

The genes that code for these mRNAs, called maternal effect genes, encode for proteins that get translated upon fertilization to establish concentration gradients that span the egg. *Bicoid* and *Hunchback* are the maternal effect genes that are most important for patterning of anterior parts (head and thorax) of the*Drosophila* embryo.*Nanos* and *Caudal* are maternal effect genes that are important in the formation of more posterior abdominal segments of the *Drosophila* embryo.

In embryos from *bicoid* mutant mothers, the head and thoracic structures are converted to the abdomen making the embryo with posterior structures on both ends, a lethal phenotype.

Cytoskeletal elements such as microtubules are polarized within the oocyte and can be used to allow the localization of mRNA molecules to specific parts of the cell. Maternally synthesized *bicoid* mRNAs attach to microtubules and are concentrated at the anterior ends of forming *Drosophila* eggs. In unfertilized eggs, transcripts are still strictly localized at the tip, but immediately after fertilization, a small mRNA gradient is formed in the anterior 20% of the eggs. Another report documents a mRNA gradient up to 40%. *nanos* mRNA also attaches to a *Drosophila* egg's cytoskeleton but is concentrated at the posterior end of the egg. *Hunchback* and *caudal* mRNAs lack special location control systems and are fairly evenly spread throughout the entire interior of the egg cells.

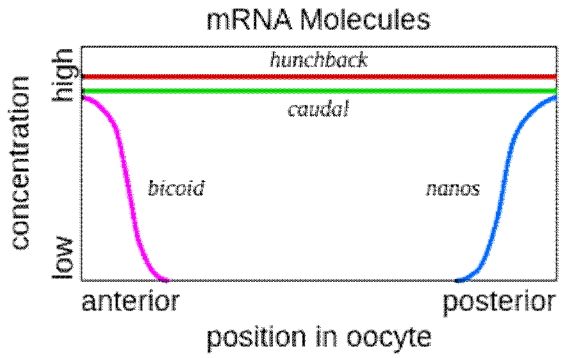


Fig. mRNA distribution.

It has been shown that the dsRNA-binding protein STAUFEN (STAU1) is responsible for guiding bicoid, nanos and other proteins, which play a role in forming the anterior-posterior axis, to the correct regions of the embryo to build gradients. When the mRNAs from the maternal effect genes aretranslated into proteins, a Bicoid protein gradient forms at the anterior end of the egg. Nanos protein forms a gradient at the posterior end. The Bicoid protein blocks translation of *caudal* mRNA so Caudal protein is of lower concentration at the anterior part of the cell and at higher concentration at the posterior part of the cell. This is of opposite direction of the Bicoid protein. The caudal protein then activates later to turn genes on to form the posterior structures during the segmentation phase. Nanos protein creates a posterior-to-anterior slope and is a morphogen that helps in abdomen formation. Nanos protein binds to the *hunchback* mRNA and blocks its translation in the posterior end of *Drosophila* embryos.

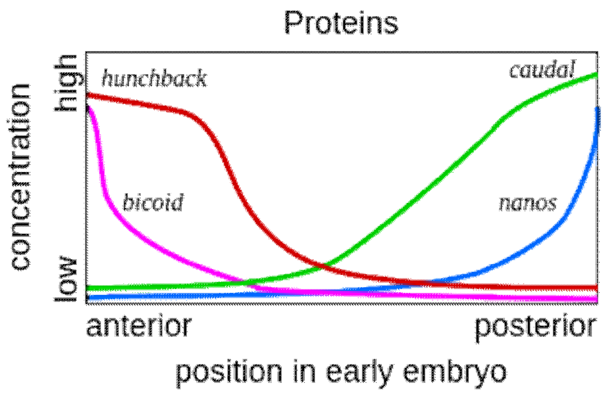


Fig. Protein distribution.

The Bicoid, Hunchback, and Caudal proteins are transcription factors. The Bicoid protein is a morphogen as well. The Nanos protein is a translational repressor protein. Bicoid has a DNA-binding homeodomain that binds both DNA and the *nanos* mRNA. Bicoid binds a specific RNA sequence in the 3' untranslated region, called the Bicoid 3'-UTR regulatory element, of *caudal* mRNA and blocks translation.

Hunchback protein levels in the early embryo are significantly augmented by new *hunchback* gene transcription and translation of the resulting zygotically produced mRNA. During early *Drosophila* embryogenesis there are nuclear divisions without cell division. The many nuclei that are produced distribute themselves around the periphery of the cell cytoplasm. Gene expression in these nuclei is regulated by the Bicoid, Hunchback, and Caudal proteins. For example, Bicoid acts as a transcriptional activator of *hunchback* gene transcription. In order for development to continue, Hunchback is needed in an area that is declining in amount from anterior to posterior. This is created by the Nanos protein whose existence is at a declining slope from posterior to anterior ends.

Gap genes

The other important function of the gradients of Bicoid, Hunchback, and Caudal proteins is in the transcriptional regulation of other zygotically expressed proteins. Many of these are the protein products derived from members of the "gap" family of developmental control genes. *giant*, *huckebein*, *hunchback*, *knirps*, *Krüppel* and *tailless* are all gap genes.

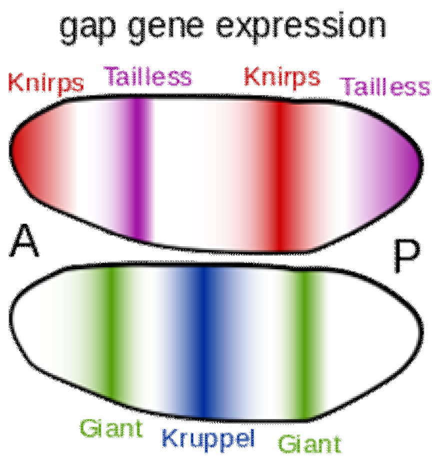


Fig. Gap genes.

Their expression patterns in the early embryo are determined by the maternal effect gene products and shown in the diagrams on the right side of this page. The gap genes are part of a larger family called the segmentation genes. These genes establish the segmented body plan of the embryo along the anterior-posterior axis. The segmentation genes specify 14 *parasegments* that are closely related to the final anatomical segments. The gap genes are the first layer of a hierarchical cascade of the segmentation control genes.

Additional segmentation genes

Two additional classes of segmentation genes are expressed after the gap gene products. The pair-rule genes are expressed in striped patterns of seven bands perpendicular to the anterior-posterior axis (see Figure, *even-skipped*). These patterns of expression are established within the syncytial blastoderm. After these initial patterning events, cell membranes form around the nuclei of the syncytial blastoderm converting it to a cellular blastoderm.

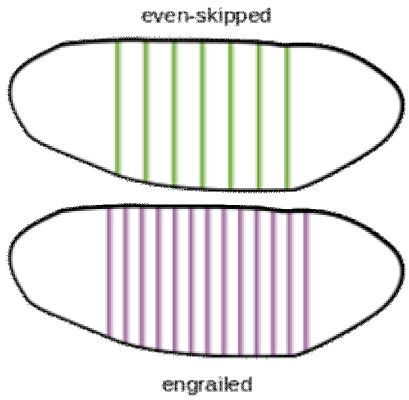


Fig. Pair rule gene.

The expression patterns of the final class of segmentation genes, the segment polarity genes, are then fine-tuned by interactions between the cells of adjacent parasegments (see the example, *engrailed*, Figure). The Engrailed protein is a transcription factor (yellow in Figure) that is expressed in one row of cells at the edge of each parasegment. This expression pattern is initiated by the pair-rule genes (like *even-skipped*) that code for transcription factors that regulate the *engrailed* gene's transcription in the syncytial blastoderm.

Cells that make Engrailed can make the cell-to-cell signaling protein Hedgehog (green in Figure). The motion of Hedgehog is limited by its lipid modification, and so Hedgehog activates a thin stripe of cells anterior to the Engrailed-expressing cells. Only cells to one side of the Engrailed-expressing cells are competent to respond to Hedgehog because they express the receptor protein Patched (blue in Figure). Cells with activated Patched receptor make the Wingless protein (red in Figure). Wingless is a secreted protein that acts on the adjacent rows of cells by activating its cell surface receptor, Frizzled.

Wingless acts on Engrailed-expressing cells to stabilize Engrailed expression after the cellular blastoderm forms. The Naked cuticleprotein is induced by Wingless to limit the number of rows of cells that express Engrailed. The short-range, reciprocal signalling by Hedgehog and Wingless, held in check by the Patched and Naked proteins, stabilizes the boundary between each segment. The Wingless protein is called "wingless" because of the phenotype of some *wingless* mutants. Wingless and Hedgehog also function in multiple tissues later in embryogenesis and also during metamorphosis.

The transcription factors that are coded for by segmentation genes regulate yet another family of developmental control genes, the homeotic selector genes. These genes exist in two ordered groups on *Drosophila* chromosome 3. The order of the genes on the chromosome reflects the order that they are expressed along the anterior-posterior axis of the developing embryo. The Antennapedia group of homeotic selector genes includes *labial*, *antennapedia*, *sex combs reduced*, *deformed*, and *proboscipedia*. Labial and Deformed proteins are expressed in head segments where they activate the genes that define head features. Sex-combs-reduced and Antennapedia specify the properties of thoracic segments. The bithorax group of homeotic selector genes control the specializations of the third thoracic segment and the abdominal segments. Mutations in some homeotic genes can often be lethal and the cycle of life will end at embryogenesis.

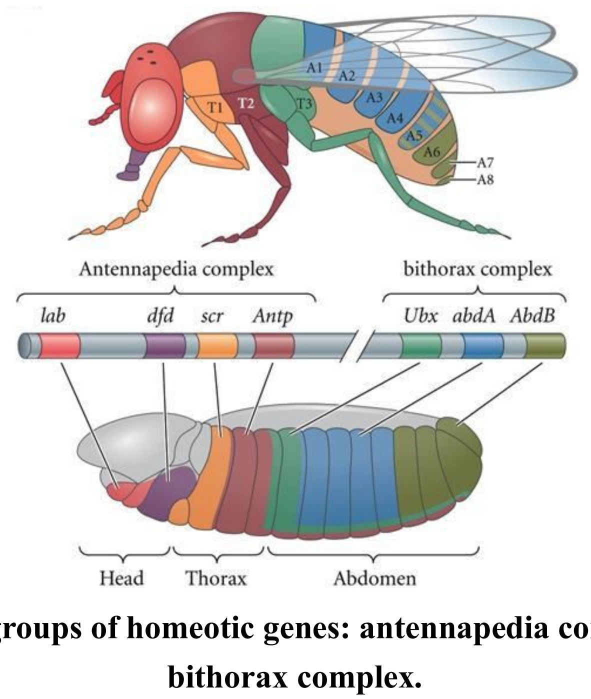


Fig. Two groups of homeotic genes: antennapedia complex and bithorax complex.

In 1995, the Nobel Prize for Physiology or Medicine was awarded for studies concerning the genetic control of early embryonic development to Christiane Nüsslein-Volhard,Edward B. Lewis and Eric Wieschaus. Their research on genetic screening for embryo patterning mutants revealed the role played in early embryologic development by*Homeobox genes* like *bicoid*. An example of a homeotic mutation is the so-called antennapedia mutation. In *Drosophila*, antennae and legs are created by the same basic "program", they only differ in a single transcription factor. If this transcription factor is damaged, the fly grows legs on its head instead of antennae. Another example is in the bithorax complex. If nonlethal mutations occur in this complex, it can cause the fly to have 2 sets of wings, instead of 1 pair of wings and 1 pair of halteres, which aid in balance in flight.

Dorsal ventral axis

Formation of the Dorsal-Ventral Axis is dependent on the ventral nuclear concentration of a maternally synthesized transcription factor called Dorsal. The determination of the dorsal side of the embryo occurs during oogenesis when the oocyte nucleus moves along microtubules from the posterior to the anterior-dorsal margin of the oocyte. The nucleus expresses a protein called Gurken which is secreted locally and thus only activates follicle cells in the dorsal region by interacting with the Torpedo receptor. This inhibits the production of Pipe protein and thus follicular cells expressing Pipe are on the ventral side. Pipe activates an extracellular protease cascade in the perivitelline space between the follicle cells and the egg which results in the cleavage of the Toll-ligand Spätzle and activation of the Toll signaling cascade on the ventral side.

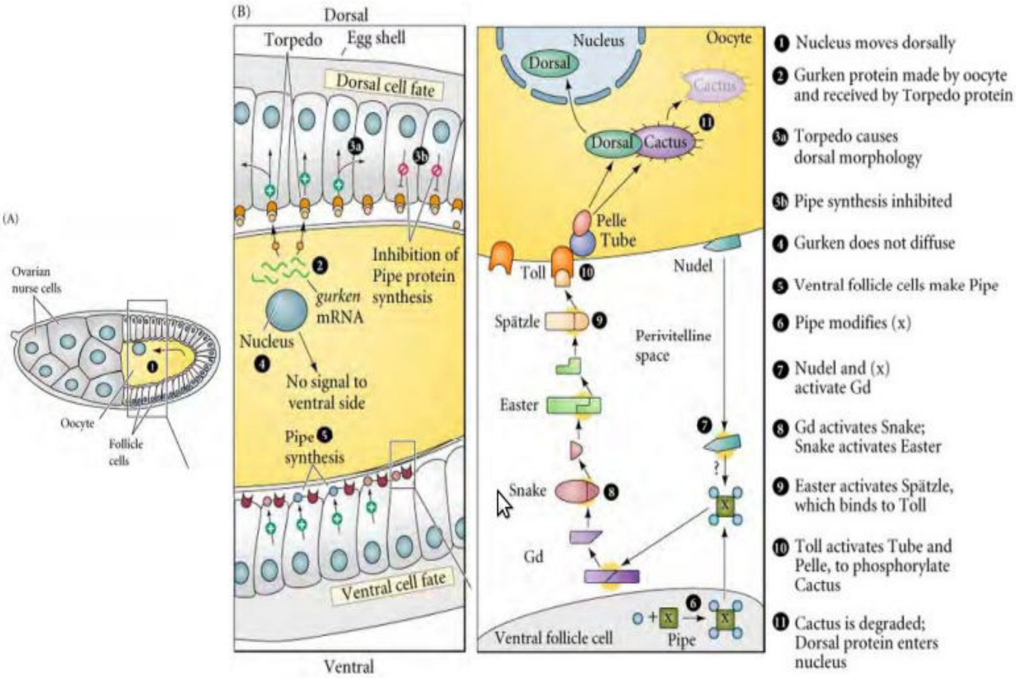


Fig. Shows cascades of dorsal ventral axis formation in Droshophila.

Dorsal protein is present throughout embryonic cytoplasm but bound to Cactus which prevents it from translocating to the nucleus. Toll signaling results in the degradation of Cactus which allows Dorsal to enter the nuclei on the ventral side of the blastoderm. Overall, a difference in the localization of the oocyte nucleus becomes a difference in the signaling state of the surrounding follicle cells which then signal to the resulting blastoderm nuclei.

Once in the nucleus, Dorsal activates different genes depending upon its nuclear concentration. This process sets up a gradient between the ventral and dorsal side of the blastoderm embryo with the repression or induction of Dorsal target genes being differentially regulated. At the ventral end of the embryo, blastoderm nuclei exposed to high concentrations of dorsal protein induce the transcription of the transcription factors *twist* and *snail* while repressing *zerknüllt* and *decapentaplegic*. This results in the formation of the mesoderm. In the lateral regions of the embryo, low nuclear concentrations of Dorsal lead to the expression of *rhomboid* which identifies future neuroectoderm. More dorsally, active Dpp signaling represses *rhomboid* thus confining it to the lateral blastoderm nuclei. At the dorsal side of the embryo, blastoderm nuclei where this is little or no nuclear dorsal protein express *zerknüllt*, *tolloid*, and *decapentaplegic* (Dpp). This leads to the specification of non-neural ectoderm and later in the blastula stage to anmioserosa. The ventral activity of the TGF-β family signaling protein Dpp is maintained by the expression of the secreted Dpp-agonist Sog (short gastrulation) in the neuroectoderm. Sog binds to and prevents Dpp from diffusing to the ventral side of the embryo and through the cleavage of Sog by Tolloid also enables a sharpening of the Dpp gradient on the dorsal side. The DV axis of *Drosophila* is due to the interaction of two gradients - a ventral concentration of nuclear Dorsal and a dorsal concentration of Dpp activity.

Axes and pattern formation in amphibian

Dorsal/ventral axis & organizer

Between fertilization and the first cleavage in *Xenopus* embryos, the cortical cytoplasm of the zygote rotates relative to the central cytoplasm by about 30 degrees to uncover (in some species) a gray crescent in the marginal or middle region of the embryo. The cortical rotation is powered by microtubules motors moving along parallel arrays of cortical microtubules. This gray crescent marks the future dorsal side of the embryo. Blocking this rotation prevents formation of the dorsal/ventral axis. By the late blastula stage, the*Xenopus* embryos have a clear dorsal/ventral axis.

In the early gastrula, most of the tissue in the embryo is not determined. The one exception is the anterior portion of the dorsal blastopore lip. When this tissue was transplanted to another part of the embryo, it developed as it normally would. In addition, this tissue was able to induce the formation of another dorsal/ventral axis. Hans Spemann named this region the organizer and the induction of the dorsal axis the primary induction.

The organizer is induced from a dorsal vegetal region called the Nieuwkoop center. There are many different developmental potentials throughout the blastula stage embryos. The vegetal cap can give rise to only endodermal cell types while the animal cap can give rise to only epidermal cell types. The marginal zone, however, can give rise to most structures in the embryo including mesoderm. A series of experiments by Pieter Nieuwkoop showed that if the marginal zone is removed and the animal and vegetal caps placed next to each other, the mesoderm comes from the animal cap and the dorsal tissues are always adjacent to the dorsal vegetal cells. Thus, this dorsal vegetal region, named the Nieuwkoop center, was able to induce the formation of the organizer.

Twinning assays identified Wnt proteins as molecules from the Nieuwkoop center that could specify the dorsal/ventral axis. In twinning assays, molecules are injected into the ventral blastomere of a four-cell stage embryo. If the molecules specifies the dorsal axis, dorsal structures will be formed on the ventral side. Wnt proteins were not necessary to specify the axis, but examination of other proteins in the Wnt pathway led to the discovery that β-catenin was. β-catenin is present in the nuclei on the dorsal side but not on the ventral side. β-catenin levels are regulated by GSK-3. When active, GSK-3 degrades free β-catenin. There are two possible molecules that might regulate GSK-3: GBP (GSK-3 Binding Protein) and Dishevelled. The current model is that these act together to inhibit GSK-3 activity. Dishevelled is able to induce a secondary axis when overexpressed and is present at higher levels on the dorsal side after cortical rotation (Symmetry Breaking and Cortical Rotation). Depletion of Dishevelled, however, has no effect. GBP has an effect when depleted and overexpressed. Recent evidence, however, showed that Xwnt11, a Wnt molecule expressed in *Xenopus*, was both sufficient and necessary for dorsal axis formation.

Mesoderm formation comes from two signals: one for the ventral portion and one for the dorsal portion. Animal cap assays were used to determine the molecular signals from the vegetal cap that are able to induce the animal cap to form mesoderm. In an animal cap assay, molecules of interest are either applied in medium that the cap is grown in or injected as mRNA in an early embryo. These experiments identified a group of molecules, the transforming growth factor-β (TGF-β) family. With dominant negative forms of TGF-β, early experiments were only able to identify the family of molecules involved not the specific member. Recent experiments have identified the *Xenopus* nodal-related proteins (Xnr-1, Xnr-2, and Xnr-4) as the mesoderm-inducing signals. Inhibitors of these ligands prevents mesoderm formation and these proteins show a graded distribution along the dorsal/ventral axis.

Vegetally localized mRNA, VegT and possibly Vg1, are involved in inducing the endoderm. It is hypothesized that VegT also activates the Xnr-1,2,4 proteins. VegT acts as a transcription factor to activate genes specifying endodermal fate while Vg1 acts as a paracrine factor.

β-catenin in the nucleus activates two transcription factors: siamois and twin. β-catenin also acts synergistically with VegT to produce high levels of Xnr-1,2,4. Siamois will act synergistically with Xnr-1,2,4 to activate a high level of the transcription factors such as goosecoid in the organizer. Areas in the embryo with lower levels of Xnr-1,2,4 will express ventral or lateral mesoderm.

Nuclear β-catenin works synergistically with the mesodermal cell fate signal to create the signaling activity of the Nieuwkoop center to induce the formation of the organizer in the dorsal mesoderm.

Organizer function

There are two classes of genes that are responsible for the organizer's activity: transcription factors and secreted proteins. Goosecoid (which has a homology between bicoid and gooseberry) is the first known gene to be expressed in the organizer and is both sufficient and necessary to specify a secondary axis.

The organizer induces ventral mesoderm to become lateral mesoderm, induces the ectoderm to form neural tissue and induces dorsal structures in the endoderm. The mechanism behind these inductions is an inhibition of the bone morphogenetic protein 4 signaling pathway that ventralizes the embryo. In the absence of these signals, ectoderm reverts to its default state of neural tissue. Four of the secreted molecules from the organizer,chordin,noggin,follistatinand Xenopus nodal-related-3 (Xnr-3), directly interact with BMP-4 and block its ability to bind to its receptor. Thus, these molecules create a gradient of BMP-4 along the dorsal/ventral axis of the mesoderm.

BMP-4 mainly acts in trunk and tail region of the embryo while a different set of signals work in the head region. Xwnt-8 is expressed throughout the ventral and lateral mesoderm. The endomesoderm (can give rise to either endoderm or mesoderm) at the leading edge of the archenteron (future anterior) secrete three factors Cerberus,Dickkopf, and Frzb. While Cerberus and Frzb bind directly to Xwnt-8 to prevent it from binding to its receptor, Cerberus is also capable of binding to BMP-4 and Xnr1. Furthermore Dickkopf binds to LRP-5, a transmembrane protein important for the signalling pathway of Xwnt-8, leading to endocytosis of LRP-5 and eventually to an inhibition of the Xwnt-8 pathway.

Anterior/posterior axis

The anterior/posterior patterning of the embryo occurs sometime before or during gastrulation. The first cells to involute have anterior inducing activity while the last cells have posterior inducing activity. The anterior inducing ability comes from the Xwnt-8 antagonizing signals Cereberus, Dickkopf and Frzb discussed above. Anterior head development also requires the function of IGFs (insulin-like growth factors) expressed in the dorsal midline and the anterior neural tube. It is believed that IGFs function by activating a signal transduction cascade that interferes and inhibits both Wnt signaling and BMP signaling. In the posterior, two candidates for posteriorizing signals include eFGF, a fibroblast growth factor homologue, and retinoic acid.

Axes and pattern formation in Chick

The dorsal/ventral axis is defined in chick embryos by the orientation of the cells with respect to the yolk. Ventral is down with respect to the yolk while animal is up. This axis is defined by the creation of a pH difference "inside" and "outside" of the blastoderm between the subgerminal space and the albumin on the outside. The subgerminal space has a pH of 6.5 while the albumin on the outside has a pH of 9.5.

The anterior/posterior axis is defined during the initial tilting of the embryo when the eggshell is being desposited. The egg is constantly being rotated in a consistent direction and there is a partial stratification of the yolk; the lighter yolk components will be near one end of the blastoderm and will become the future posterior. The molecular basis of the posterior is not known, however, the accumulation of cells eventually results in the posterior marginal zone (PMZ).

The PMZ is the equivalent of the Nieuwkoop center is that its role is to induce Hensen's node. Transplantation of the PMZ results in induction of a primitive streak, however, PMZ does not contribute to the streak itself. Similar to the Nieuwkoop center, the PMZ expresses both Vg1 and nuclear localized β-catenin.

The Hensen's node is equivalent to the organizer. Transplantation of Hensen's node results in the formation of a secondary axis. Hensen's node is the site where gastrulation begins and it becomes the dorsal mesoderm. Hensen's node is formed from the induction of PMZ on the anterior part of the PMZ called Koller's sickle. When the primitive streak forms, these cells expand out to become Hensen's node. These cells express goosecoid consistent with their role as the organizer.

The function of the organizer in chick embryos is similar to that of amphibians and fish, however, there are some differences. Similar to the amphibians and fish, the organizer does secrete Chordin, Noggin and Nodal proteins that antagonize BMP signaling and dorsalize the embryo. Neural induction, however, does not rely entirely on inhibiting the BMP signaling. Overexpression of BMP antagonists is not enough induce formation of neurons nor overexpressing BMP block formation of neurons. While the whole story is unknown for neural induction, FGFs seem to play a role in mesoderm and neural induction. The anterior/posterior patterning of the embryo requires signals like cereberus from the hyboplast and the spatial regulation of retinoic acid accumulation to activate the 3' Hox genes in the posterior neuroectoderm (hindbrain and spinal cord).

14.5 Vulva formation in *Caenorhabditis elegans*

Single cells can induce changes in their neighbors

The tiny nematode *Caenorhabditiselegans*is used as a model organism in many biological studies, but it is especially useful for studying development. It normally lives in the soil, where it feeds on bacteria, but can also grow in the laboratory if supplied with its food source. The process of development from fertilized egg to larva takes only about 8 hours, and the worm reaches the adult stage in just 3.5 days. The process is easily observed using a low-magnification dissecting (Figure). For all these reasons, *C. elegans* is a favorite experimental organism. The development of *C. elegans*does not vary, so it has been possible to identify the source of each of the 959 somatic cells of the adult form.

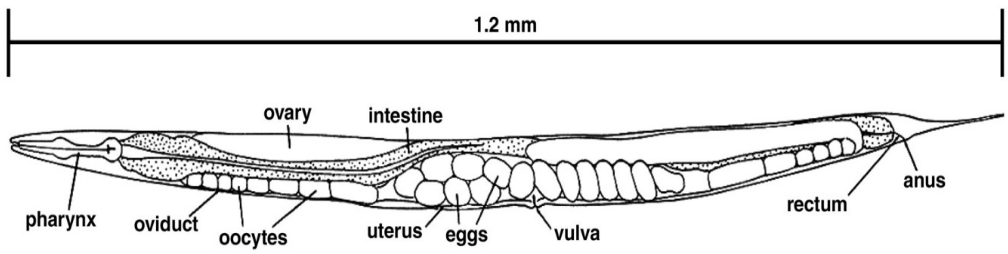


Fig. Anatomy of *Caenorhabditis elegans.*

The adult nematode is *hermaphroditic,* containing both male and female reproductive organs. It lays eggs through a pore called the *vulva* on the ventral (belly) surface. During development, a single cell, called the *anchor cell*, induces the vulva to form. If the anchor cell is destroyed by laser surgery, no vulva forms. The eggs develop inside the parent, and a “bag of worms”, which eventually consume the parent, results.

The anchor cell controls the fates of six cells on the animal’s ventral surface through two molecular switches. Each of these cells has three possible fates. It may become a primary vulval precursor cell, a secondary vulval precursor cell, or simply part of the worm’s surfaces- an epidermal cell (Figure). The anchor cell produces an inducer that diffuses out of the cell and interacts with adjacent cells. Cells that receive enough of the inducer become vulval precursor cells; cells slightly farther from the anchor cell become epidermis. The first molecular switch, controlled by the inducer from the anchor cell, determines whether a cell takes the "track" toward becoming part of the vulva or the track toward becoming epidermis.

The cell closet to the anchor cell, having received the most inducer, differentiates into the primary vulval precursor cell. It produces its own inducer, which acts on the two neighboring cells and directs them to become secondary vulval precursor cells. Thus, the primary vulval precursor cell controls a second molecular switch, determining whether a vulval precursor will take the primary track or the secondary track. The two inducers control the activation or inactivational specific genes in the responding cells.

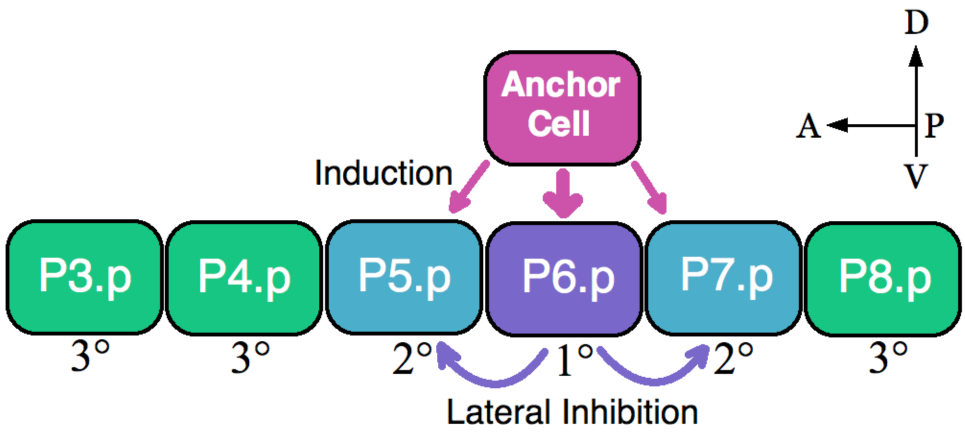


Fig. Model for the determination of the VPCs (cells P3.p-P8.p) in C. elegans. An inductive signal from the anchor cell via LIN-3 determines P6.p to adopt the 1°. Then, the lateral signal LIN-12 causes P5.p and P5.7 to become 2°. The other VPCs do not receive an inductive signal and are fated as 3°. Anterior is to the left.

Much of development is controlled by molecular switches that allow a cell to proceed down one of two alternative tracks. The primary inducer released by the C. elegans anchor cell appears to be a growth factor (EFG). The nematode growth factor called LIN-3 binds to a receptor on the surface of a potential vulval precursor cell. This binding sets in motion a signal transduction cascade involving the Ras protein and MAP kinases. The end result is increased transcription of the genes involved in the differentiation of vulval cells.

The development of the vulva in C. elegans offers several examples of induction on the cellular level. The formation of the anchor cell is mediated by the lin-12 gene, the C. elegans hermaphrodites two adjacent cells, Z1.ppp and Z4.aaa, have the potential to become the anchor cell. They interact in a manner that causes one of them to become the anchor cell while the other one becomes the precursor of the uterine tissue. In recessive lin-12 mutants, both cells become anchor cells, while in dominant mutations both cells become uterine precursors.

Studies using genetic mosaics and cell ablations have shown that this decision is made in the second larval stage and that the LIN-12 gene only needs to function in that cell destined to become the uterine precursor cell. The presumptive anchor cell does not need it. Seydoux and Greenwald (1989) speculate that these two cells originally synthesize both the signal for uterine differentiation (the LAG-2 protein, homologous to Delta in Drosophila) and the receptor for this molecule (the LIN-12 protein, homologous to Notch). During a particular time in larval development the cell that by chance is secreting more LAG-2 causes its neighbor to cease its production of this differentiation signal and to increase its production of LIN-12 protein. The cell secreting LAG-2 becomes the gonadal anchor cell while the cell receiving the signal through its LIN-12 protein becomes the ventral uterine precursor cell. Thus the two cells are thought to determine each other prior to their respective differentiation events.

The anchor cell/ventral uterine precursor decision illustrates two important aspects of determination in two originally equivalent cells. First the initial difference between the two cells is creates by chance. Second this initial difference is reinforced by feedback.

The LIN-12 protein will be used again during vulva formation. It is activated by the primary vulval lineage to stop the lateral vulval cells from forming the central vulval phenotype.

14.6 Eye lens induction in vertebrates

Eye formation in the human embryo begins at approximately 3 weeks into embryonic development and continues through the tenth week. Cells from both the mesodermal and the ectodermal tissues contribute to the formation of the eye. Specifically, the eye is derived from the neuroepithelium, surface ectoderm, and the extracellular mesenchyme which consists of both the neural crest and mesoderm. Neuroepithelium forms the retina, ciliary body, iris, and optic nerves. Surface ectoderm forms the lens, corneal epithelium and eyelid. The extracellular mesenchyme forms the sclera, cornea, blood vessels, muscles, and vitreous.

The eye begins to develop as a pair of optic vesicles on each side of the forebrain at the end of the 4th week of pregnancy. Optic vesicles are outgrowings of the brain which make contact with the surface ectoderm and this contact induces changes necessary for further development of the eye. Through a groove at the bottom of the optic vesicle known as choroid fissure the blood vessels enter the eye. Several layers such as the neural tube, neural crest, surface ectoderm, and mesoderm contribute to the development of the eye.

Eye development is initiated by the master control gene Pax-6, a homeobox gene known as Andridia in humans, small eye in mouse, and eyeless in Drosphilia. The Pax-6 gene locus is a transcription factor for the various genes and growth factors involved in eye formation. Eye morphogenesis begins with the evagination, or outgrowth, of the optic grooves or sulci. These two grooves in the neural folds transform into optic vesicles with the closure of the neural tube. The optic vesicles then develop into the optic cup with the inner layer forming the retina and the outer portion forming the retinal pigment epithelium. The middle portion of the optic cup develops into the ciliary body and iris. During the invagination of the optic cup, the ectoderm begins to thicken and form the lens placode, which eventually separates from the ectoderm to form the lens vesicle at the open end of the optic cup. Further differentiation and mechanical rearrangement of cells in and around the optic cup gives rise to the fully developed eye.

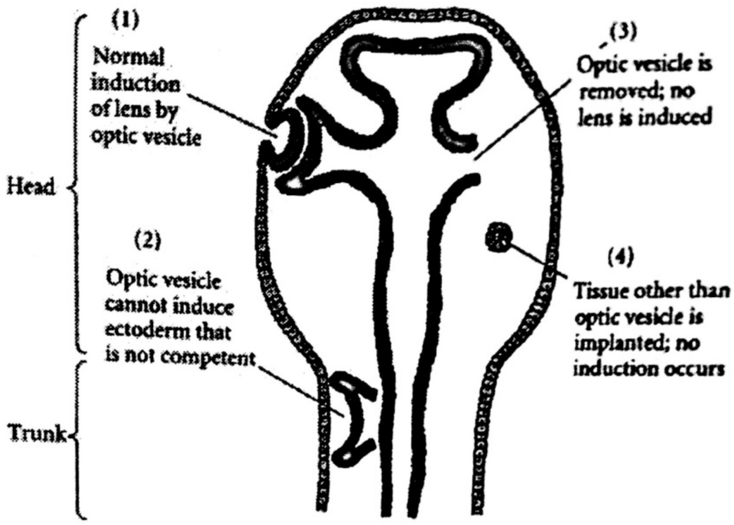
This development is an example of sequential inductions where the organ is formed from three different tissues:

Neural tube ectoderm (neuroectoderm)

First, there is an outpocketing of the neural tube called optic vesicles. Development of the optic vesicles starts in the 3-week embryo, from a progressively deepening groove in the neural plate called the optic sulcus. Some studies suggest this mechanism is regulated by RX/RAX transcription factor. The proteins Wnt and FGF (fibroblast growth factor) play a part in this early stage and are regulated by another protein called Shisa. As this expands, the rostral neuropore (the exit of the brain cavity out of the embryo) closes and the optic sulcus and the neural plate becomes the optic vesicle. Optic nerves arise from connections of the vesicles to the forebrain.

Surface ectoderm

Lens development is closely related to optic vesicle development. The interaction between the growing vesicle and the ectoderm causes the ectoderm to thicken at that point. This thickened portion of the ectoderm is called the lens placode. Next, the placode invaginates and forms a pouch referred to as the lens pit. Scientists are studying the tension forces necessary for invagination of the lens placode and current research suggests that microfilaments might be present in early retinal cells to allow for invagination behavior. Research has also shown that Rho GTPase dependent filopodia from the precursor lens ectoderm play an important role in the formation of the lens pit. Eventually, the pit becomes completely enclosed. This enclosed structure is the lens vesicle. Studies have shown that lens development requires the presence of the Pax6 gene, which is the master regulatory gene for eye morphogenesis. This master regulatory gene is not necessary for the closely associated optic vesicle development. Additionally, Ras activation has been shown to be sufficient for starting lens differentiation, but not enough for its completion.



The optic vesicles then begin to form the optic cup. Optic cup morphogenesis is the invagination process occurring after neuroectoderm movement forms the spherical optic vesicle. Invagination is when a tissue folds back on itself. Over the course of approximately 12 hours, the distal end of the optic vesicle inner layer begins to flatten. Over the following 18 hours, both the inner and outer layers begin to flex inward at sharp angles, beginning the formation of a C-shaped edge. The final 18 hours involve continuing this apically convex invagination to form the optic cup. At this point, morphologies such as columnar epithelial cells, pseudo-stratified cells, and apically narrow wedge-shaped cells can be observed.

The inner layer of the optic cup is made of neuroepithelium (neural retina), while the outer layer is composed of retinal pigment epithelium (RPE). Experiments have determined that RPE cell differentiation and maintenance requires interaction with neighboring tissues, most likely canonical Wnt signaling, while neural retina differentiation is driven by tissue-autonomous factors.

Bone morphogenic proteins (BMPs) are important regulators of optic cup development. In fact, research studies have shown that BMP agonists and antagonists are necessary for precision of optic cup development. Interactions between tissues and signaling pathways also play a major role in morphogenesis of the optic cup.

It is of interest to note that research has shown isolating the optic cup from neighboring tissue after completed invagination in tissue culture medium can lead to the development of most major parts of the eye, including photoreceptors, ganglion cells, bipolar cells, horizontal cells, amacrine cells and Muller glia. This indicates that morphogenesis of the optic cup occurs independently of external cues from its environment, including presence of lens. However, the lens is necessary to act as an inducer for the ectoderm to transform it into the cornea.

Neural crest

Neural crest cells are themselves derived from the ectoderm and lie close to the neural tube:

- sclera
- Cornea: Descemet's membrane and endothelium
- connective tissue and bony structure of the orbit

Mesoderm

Mesoderm contributes to the following structures:

- extraocular muscles

- endothelial lining of blood vessels of the eye
- blood vessels in sclera & choroid
- Sclera & Choroid
- Vitreous
- Suspensory fibres
- Cornea: Bowman's membrane and stroma

Developmental cascade

According to Liem et al., the organogenesis of the eye is pointed out as an example of a developmental cascade of inductions. The eye is essentially a derivative of the ectoderm from the somatic ectoderm and neural tube, with a succession of inductions by the chordamesoderm.

Chordamesoderm induces the anterior portion of the neural tube to form the precursors of the synapomorphic tripartite brain of vertebrates, and it will form a bulge called the diencephalon. Further induction by the chordamesoderm will form a protrusion: the optic visicle. This visicle will be subsequently invaginated by means of further inductions from the chordamesoderm. The optic vesicle will then induce the ectoderm that thickens (lens placode) and further invaginates to a point that detaches from the ectoderm and forms a neurogenic placode by itself. The lens placode is affected by the chordamesoderm making it to invaginate and forms the optic cup composed by an outer layer of neural retina and inner layer the pigmented retina that will unite and form the optic stalk. The pigmented retina is formed by rods and cones and composed of small cilia typical of the ependymal epithelium of the neural tube. Some cells in the lens vesicle will be fated to form the cornea and the lens vesicle will develop completely to form the definitive lens. Iris is formed from the optic cup cells.

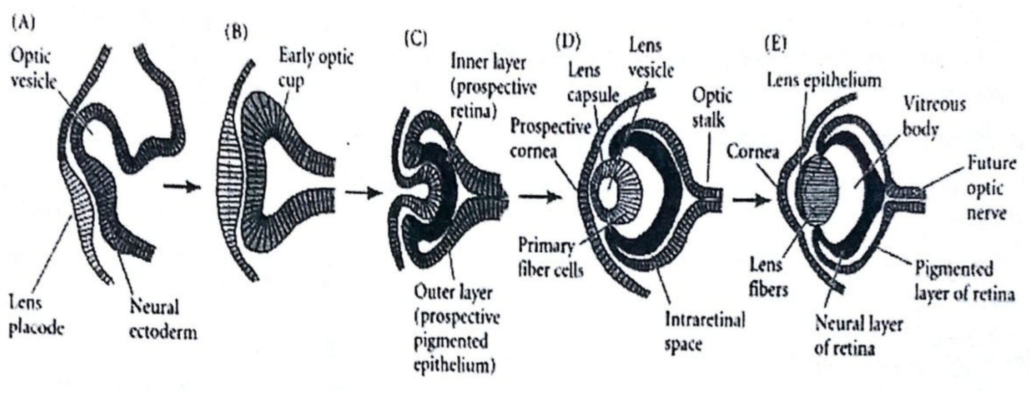


Fig. Shows schematic diagram of the induction of the vertebrate lens.

Responsivity of head epidermis

Only the epidermis in the head is competent to respond to the signal from the optic vesicles. Both the optic vesicle and the head epidermis are required for eye development. The competence of the head epidermis to respond to the optic vesicle signals comes from the expression of Pax6 in the epidermis. Pax6 is necessary and sufficient for eye induction. This competenece is acquired gradually during gastrulation and neurulation from interactions with the endoderm, mesoderm, and neural plate.

Regulation and inhibition

Sonic hedgehog reduces the expression of Pax6. When Shh is inhibited during development, the domain of expression for Pax6 is expanded and the eyes fail to separate causing cyclopia. Overexpression of Shh causes a loss of eye structures.

Retinoic acid generated from vitamin A in the retina plays an essential role in eye development as a secreted paracrine signal which restricts invasion of perioptic mesenchyme around the optic cup. Vitamin A deficiency during embryogenesis results in anterior segment defects (particularly cornea and eyelids) that lead to vision loss or blindness.There is some evidence that LMX1B plays a role in periocular mesenchymal survival.

14.7 Limb development and regeneration in vertebrates

Pattern formation is the development of a body according to a specific and planned spatial arrangement. The vertebrate limb is an extremely complex organ with an asymmetrical arrangement of parts. There are three major axes to consider one of which is the proximal (close) to distal (far) axis. The bones of the limb are it wing, foot, hand or flipper consist of a proximal stylopod (humerus/femur) adjacent to the body wall, a zeugopod (radius-ulna/tibia-fibula) in the middle region, and a distal autopod (carpals- fingers/tarsals-toes). Originally these structures are cartilaginous but eventually most of the cartilage is replaced by bone.

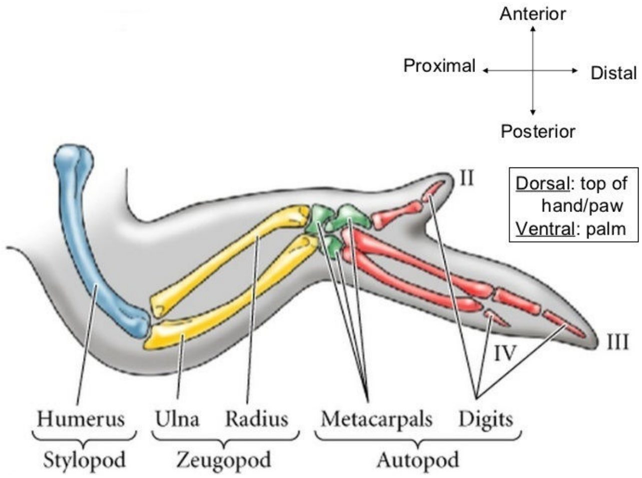


Fig. Shows three regions of vertebrate limb.

The positions of each of the bones and muscles in the limb are precisely organized. The second axis is the anterior (front) to posterior (back) axis. Our little fingers for instance mark the posterior side while our thumbs are in the anterior. In humans it is obvious that each hand develops as a mirror image of the other. The third axis is the dorsal ventral axis. The palm (ventral) is readily distinguishable from the knuckles (dorsal).

The positional information needed to construct a limb has to function in a three dimensional coordinate system. During the past decade particular proteins have been identified that play a role in the formation of each of these limb axes. The proximal distal (shoulder finger, hip toe) axis appears to be regulated by the fibroblast growth factor (FGF) family of proteins. The anterior posterior (thumb pinky) axis seems to be regulated by the sonic hedgehog protein and the dorsal ventral (knuckle palm) axis is regulated at least in part by Wnt 7a.

The interactions of these proteins determine the differentiation of the cell types and also mutually support one another.

Formation of the limb bud

Specification of the limb fields Hox genes and retinoic acid

Limbs will not form just anywhere along the body axis. Rather there are discrete positions where limb fields are generated. Using the techniques researchers have precisely localized the limb fields of many vertebrate species. Interestingly in all land vertebrates there are only four limb buds per embryo and they are always opposite each other with respect to the midline. Although the limbs of different vertebrates differ with respect to which somite level they arise from their position is constant with respect to the level of Hox gene expression along the anterior posterior axis. For instance in fishes (in which the pectoral and pelvic fins correspond to the anterior and posterior limbs respectively) amphibians, birds and mammals the forelimb buds are found at the most anterior expression region of Hoxc-6 the position of the first thoracic vertebra. The lateral plate mesoderm in the limb field is also special in that it will induce myoblasts to migrate out from the somites and enter the limb bud. No other region of the lateral plate mesoderm will do that.The limb bud has to be specified as being those of either the forelimb or the hindlimb. The limb field is a region specified by expression of certain homeobox (*Hox*) genes and Tbx genes; Tbx5 for forelimb and Tbx4 for hindlimb.

Retinoic acid appears to be critical for the initiation of limb bud outgrowth , since blocking the synthesis of retinoic acid with certain drugs prevents limb bud initiation. Bryant and Gardiner (1992) suggested that a gradient of retinoic acid along the anterior posterior axis might activate certain homeotic genes in particular cells and thereby specify them to become included in the limb field. The source of this retinoic acid is probably Hensen's node. The specification of limb fields by retinoic acid activated Hox gene might explain a bizarre observation made by Mohanty Hejmadi and colleagues (1992) and repeated by Maden (1993). When the tails of tadpoles were amputated and the stumps exposed to retinoic acid during the first days of regeneration the tadpoles regenerated several legs from the tail stump. It appears that the retinoic acid caused a homeotic transformation in the regenerating tail by respecifying the tail tissue as a limb forming pelvic region.

The lateral plate cells produce the cartilaginous and skeletal portions of the limb while the myotome cells produce the muscle components. The lateral plate mesodermal cells secrete a fibroblast growth factor (FGF7 andFGF10, presumably) to induce the overlying ectoderm to form an important organizing structure called the apical ectodermal ridge(AER).

This ridge runs along the distal margin of the limb bud and will become a major signalling center for the developing limb. Its roles include:

a. Maintaining the mesenchyme beneath it in a plastic, proliferating phase that enables the linear (proximal- distal) growth of the limb;
b. Maintaining the expression of those molecules that generate the anterior posterior (thumb- pinky) axis and
c. Interacting with the proteins specifying the anterior posterior and dorsal ventral axis so that each cell is given instructions on how to differentiates.

The AER reciprocatively secretes FGF8 and FGF4 which maintains the FGF10 signal and induces proliferation in the mesoderm. The position of FGF10 expression is regulated by Wnt8c in the hindlimb and Wnt2b in the forelimb. The forelimb and the hindlimb are specified by their position along the anterior/posterior axis and possibly by two T-box containing transcription factors: Tbx5 and Tbx4, respectively.Programmed cell death removes the "webbing" between the digits and joints. BMP signalling induces cell death and Noggin blocks cell death in the digits.

Generating the proximal – distal axis of the limb

The proximal distal growth and differentiation of the limb bud is made possible by a series of interactions between the limb bud mesenchyme and the AER. These interactions were demonstrated by the results of several experiments on chick embryos:

1. If the AER is removed at any time during limb development further development of distal limb skeletal elements ceases.
2. If an extra AER is grafted onto an existing limb bud, supernumerary structures are formed, usually toward the distal end of the limb.
3. If leg mesenchyme is placed directly beneath the wing AER, distal hindlimb structures (toes) develop at the end of the limb. However, if this mesenchyme is placed farther from the AER the hindlimb mesenchyme becomes integrated into wing structures.
4. If limb mesenchyme is replaced by nonlimb mesenchyme beneath the AER, the AER regresses and limb development ceases.

The progress zone : The mesodermal component

The proximal- distal axis is defined only after the induction of the apical ectodermal ridge by the underlying mesoderm. The limb bud elongates by means of the proliferation of the mesenchyme cells underneath the AER. This region of cell division is called the progress zone, and it extends about 200 µm in from the AER.

The mitotic state of the progress zone is maintained by interactions between the FGF proteins of the progress zone and of the AER. FGF10 secretion by the mesenchyme cells induce the AER and it also induces the AER to express FGF8. The FGF8 secreted by the AER reciprocates by maintaining the mitotic activity of the progress zone mesenchyme cells.

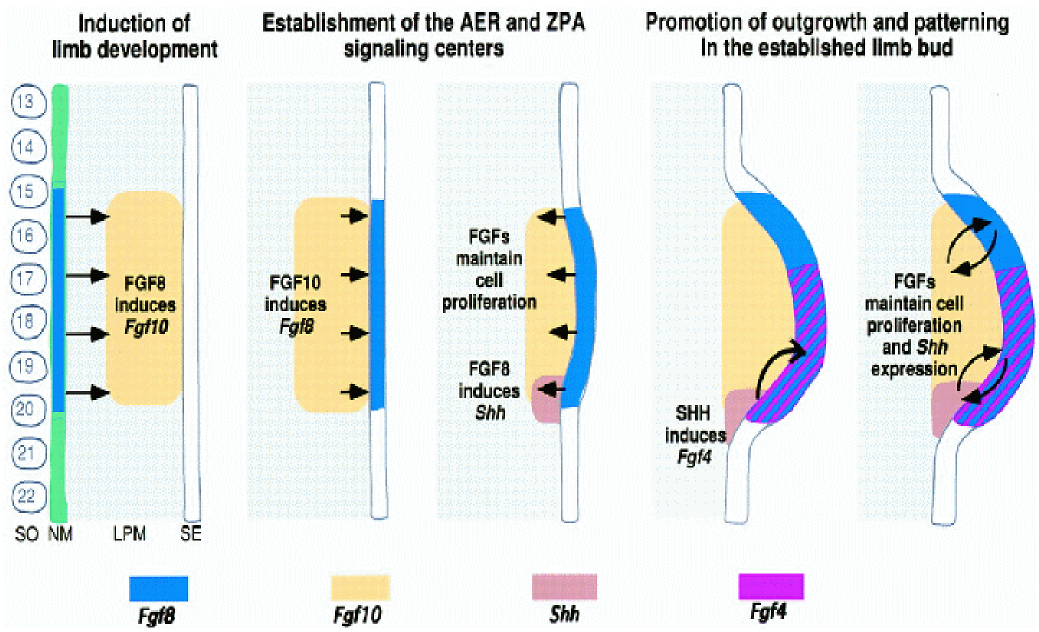


Fig. Shows the cascade of proximal distal axis formation of the limb.

The type of structure formed along the proximal distal axis is specified by the Hox genes. The products of the Hox genes have already played a role in specifying the place where the limbs will form. Now they will play a second role in specifying whether a particular mesenchymal cell will become stylopod, zeugopod or autopod.

Specification of the Anterior- Posterior limb axis

The zone of polarizing activity

The specification of the anterior posterior axis of the limb is the earlist change from the pluripotent condition. Several experiments suggest that the anterior posterior axis is specified by a small block of mesodermal tissue near the posterior junction of the young limb bud and the body wall. This region of the mesoderm has been called the zone of polarizing activity (ZPA).

When this tissue is taken from a young limb bud and transplanted into a position on the anterior side of another limb bud, the number of digits of the resulting wing is doubled. Moreover, the structures of the extra set of digits are mirror images of the normally produced structures, but the information is now coming from both an anterior and a posterior direction.

The Zone of Polarizing Activity (ZPA) in the limb bud has pattern-organizing activity by action of a morphogen gradient of Sonic hedgehog(Shh). Shh is both sufficient and necessary to create the ZPA and specify the anterior/posterior pattern in the distal limb (Shh is not necessary for the polarity of the stylopod). Shh is turned on in the posterior through the early expression of Hoxd genes, the expression of Hoxb8, and the expression dHAND. Shh is maintained in the posterior though a feedback loop between the ZPA and the AER. Shh induces the AER to produce FGF4 and FGF8 which maintains the expression of Shh.

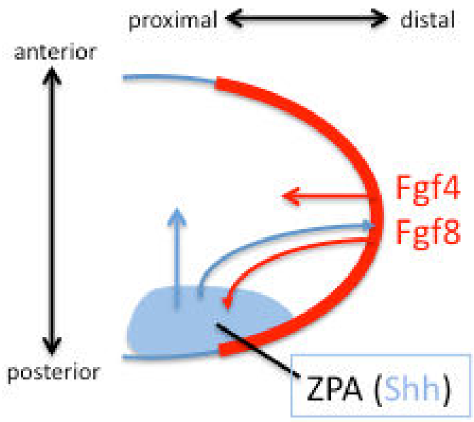


Fig. Shows the cascade of anterior posterior axis formation in vertebrate limb.

Digits 3,4 and 5 are specified by a temporal gradient of Shh. Digit 2 is specified by a long-range diffusible form of Shh and Digit 1 does not require Shh. Shh cleaves the Ci/Gli3 transcriptional repressor complex to convert the transcription factor Gli3 to an activator which activates the transcription of HoxD genes along the anterior/posterior axis. Loss of the Gli3 repressor leads to the formation of generic (non-individualized) digits in extra quantities.

Specification of the dorsal – ventral axis

Dorsal/Ventral patterning arises from Wnt7a signals in the overlying ectoderm not the mesoderm. Wnt7a is both necessary and sufficient to dorsalize the limb. Wnt7a also influences the anterior/posterior axis and loss of Wnt7a causes the dorsal side of limbs to become ventral sides and causes missing posterior digits. Replacing Wnt7a signals rescues this defect. Wnt7a is also required to maintain expression of Shh.Wnt-7a also causes Lmx-1, a Lim Hox gene (and thus a transcription factor), to be expressed. Lmx-1 is involved in dorsalisation of the limb, which was shown by knocking out the Lmx-1 gene in mice.

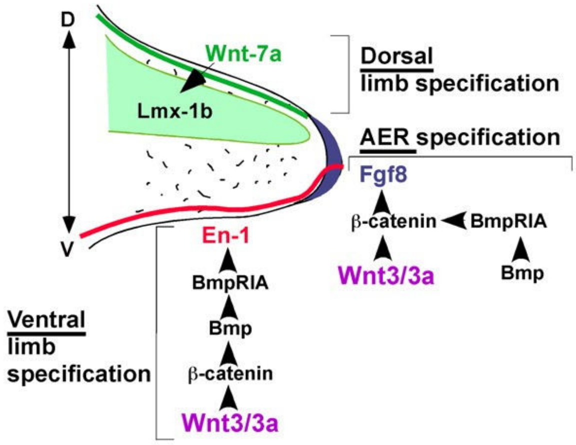


Fig. Specification of dorsal ventral axis in vertebrate limb.

The mice lacking the Lmx-1 produced ventral skin on both sides of their paws. There are other factors thought to control the DV patterning; Engrailed-1 represses the dorsalizing effect of Wnt-7a on the ventral side of the limbs.

Cell death and the formation of digits and joints sculpting the autopod

Cell death plays a role in sculpting the limb. Indeed, it is essential if our joints are to form and if our fingers are to become separate. The death (or lack of death) of specific cells in the vertebrate limb is genetically programmed and has been selected for during evolution.

One such case involves the webbing or nonwebbing of feet. The difference between a chicken's feet and that of a duck is the presence or absence of cell death between the digits. Saunders and co-workers have shown that after a certain stage, chick cells between the digit cartilage are destined to die and will do so even if transplanted to another region of the embryo or placed into culture. Before that time however transplantation to a duck limb will save them.

Between the time when the cell's death is determined and when death actually takes place, levels of DNA, RNA and protein synthesis in the cell decrease dramatically.

In addition to the inter digital necrotic zone, there are three other regions that are "sculpted" by cell death. The ulna and radius are separated from each other by an interior necrotic zone, and two other regions, the anterior and posterior necrotic zones, further shape the end of the limb. Although these zones are said to be "necrotic" this term is a holdover from the days when no distinction was made between necrotic cell death and apoptotic cell death. These cells die by apoptosis and the death of the inter digital tissue is associated with the fragmentation of their DNA.

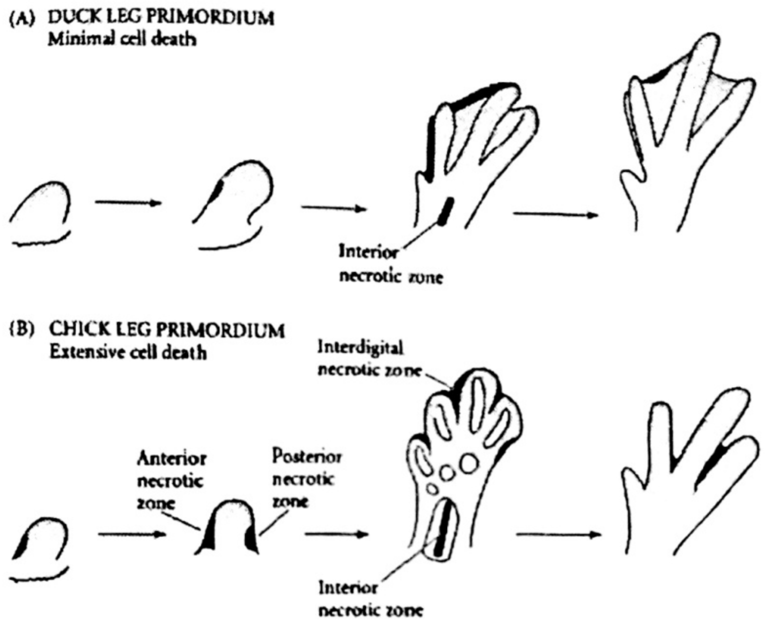


Fig. Shows Cell death and the formation of digits and joints sculpting the autopod.

The signal for apoptosis in the autopod is probably provided by the BMP proteins. BMP2, BMP4 and BMP7 are each expressed in the interdigital mesenchyme and blocking BMP signalling prevents interdigital apoptosis. Since these BMPs are expressed throughout the progress zone mesenchyme, it is thought that cell death would be the “default” state unless there was active suppression of the BMPs. This suppression may come from the Noggin protein, which is made in the developing digits and in the perichondrial cells surrounding them. If noggin is expressed throughout the limb bud, no apoptosis is seen.

Regeneration in vertebrates

Regeneration can be defined as the natural ability of living organisms to replace worn out parts, repair or renew damaged or lost parts of the body, or to reconstitute the whole body from a small fragment during the post embryonic life of an organism. Regeneration is thus also a developmental process that involves growth, morphogenesis and differentiation.

If the tail of a house lizard is cut, the missing part develops again from the remaining part of the tail. In some cases, regeneration is so advanced that an entire multicellular body is reconstructed from a small fragment of tissue. Our body spontaneously loses cells from the surface of the skin and replaced by newly formed cells. This is due to regeneration. Regeneration can either be complete where the new tissue is the same as the lost tissue, or incompletewhere after the necrotic tissue comes fibrosis.

Regenerative capacity in Animal Group

The capacity of regeneration varies in its extent in various animal groups. Regenerative capacity is very high among the protozoan, sponges and coelenterates.

Invertebrates

In sponges, the entire body can be reconstructed from isolated body cells. The cells rearrange and reorganize to form bilayered sponge body wall.In hydra and planaria, small fragments of the body can give rise to a whole animal. When a hydra or a planaria is cut into many pieces, each individual part regenerates into a whole individual.

Many arthropods (e.g., spiders, crustaceans, insect larvae, etc) can regenerate limbs only. Regeneration is faster in the young than in the adults. Regenerated part may not always be similar to the part lost. This type of regeneration is called heteromorphosis.

Echinoderms (like starfish, brittle star, sea lilly)exhibit autotomy (In some animals like starfish, some part of the body is broken off on being threatened by a predator. This phenomenon of self-mutilation of the body is called autotomy). They can regenerate arms and parts of te body.

Vertebrates

- Fishes: Lamprey can regenerate its lost tail. Some fishes have the ability to regenerate parts of its fins.
- Amphibians: The regeneration power is well marked in urodel amphibians like salamanders, newts and their axolotl larvae. They can regenerate limbs, tail, external gills, jaws, parts of eye like lens and retina. Tail and limb regeneration is found in the larval stages of frogs and toads.
- Reptiles: Lizards exhibit autotomy. When threatened, the lizard detaches its tail near the base to confuse its predator and later regenerates a new tail. The new tail differs from the old one in its shape, absence of vertebrae and the kind of scales covering it.
- Birds: Regeneration is restricted to parts of the beak.

- Mammals: Regeneration is restricted to tissues only. External parts are not regenerated. Skin and skeletal tissues possess great power of regeneration. The liver has the maximum capacity of regeneration. If one kidney is damaged or removed, the other enlarges to compensate the lost kidney. This is called as compensatory hypertrophy.

  Regeneration is a usual form of asexual reproduction in several lower groups of animals.

Types of Regeneration

Morphallaxis

In this type, regeneration occurs mainly by the remodelling of existing tissues and the re-establishment of boundaries, thus involving very little new growth. As a result, the regenerated individual is much smaller initially. It subsequently increases its size and becomes normal after feeding. This type of regeneration is known as morphallaxis or morphallactic regeneration.

Example: Regeneration of hydra from a small fragment of its body.

Epimorphosis

In this type, regeneration involves dedifferentiation of adult structures in order to form an undifferentiated mass of cells. They are highly proliferating and accumulate under the epidermis, which has already expanded. Within two days, bulge transforms into a conical hump. This lump of dedifferentiated cells along with the epidermal covering is called regeneration bud or regeneration blastema. The dedifferential cells continue to proliferate and finally redifferentiate to form a rudiment of the limb. The rudiment eventually transforms into a limb. This type of regeneration is known as epimorphosis or epimorphic regeneration.

Example: Limb regeneration in amphibians.

An internal type which occurs between the above two types of regeneration is compensatory regeneration. Here the cells divide but do not form an undifferentiated mass of cells. Instead they produce cells similar to themselves.

Regeneration of a Limb of a Newt

The mechanism of regeneration can be studied from limb regeneration in salamander. This involves the following stages,

- Wound healing: The epidermal cells from the edges of the wound migrate and spread over the exposed surface. This is known as wound healing.
- Blastema formation: A few days later, undifferentiated cells accumulate inside the epidermis, resulting in a bulge. This is known as regeneration bud or blastema.
- Redifferentiation and morphogenesis: The blastema develops rudiments of the lost organ, like the digits which grow into new digits.
- Growth: The regenerated limb increases and attains the size of a normal limb.
- In planarians and in Hydra, there are undifferentiated cells called neoblasts which multiply and then migrate from the deeper parts of the body to the cut surface.

Compensatory regeneration

In this type of regeneration the cells divide but maintain their differentiated functions. They produce cells similar to themselves and do not form a mass of undifferentiated tissue. This type of regeneration is characteristics of the mammalian liver.

14.8 Differentiation of neurons

Neurulation refers to the folding process in vertebrate embryos, which includes the transformation of theneural plate into the neural tube. The embryo at this stage is termed the neurula.The process begins when the notochord induces the formation of the central nervous system (CNS) by signalling the ectoderm germ layer above it to form the thick and flat neural plate. The neural plate folds in upon itself to form the neural tube, which will later differentiate into the spinal cord and the brain, eventually forming the central nervous system.

Different portions of the neural tube form by two different processes, called primary and secondary neurulation, in different species.

In primary neurulation, the cells surrounding the neural plate direct the neural plate cells to proliferate, invaginate and pinch off from the surface to form a hollow tube.Primary neurulation begins after the neural plate forms. The edges of the neural plate start to thicken and lift upward, forming the neural folds. The center of the neural plate remains grounded, allowing a U-shaped neural groove to form. This neural groove sets the boundary between the right and left sides of the embryo. The neural folds pinch in towards the midline of the embryo and fuse together to form the neural tube.

Primary neurulation divides the ectoderm into three cell types:

- The internally located neural tube
- The externally located epidermis
- The neural crest cells, which develop in the region between the neural tube and epidermis but then migrate to new locations

In secondary neurulation, the neural tube arises from a solid cord of cells that sinks into the embryo and subsequently hollows out to form a hollow tube.

Primary neurulation occurs in response to soluble growth factors secreted by the notochord. Ectodermal cells are induced to formneuroectoderm from a variety of signals. Ectoderm sends and receives signals of bone morphogenetic protein 4 (BMP4) and cells which receive BMP4 signal develop into epidermis. The inhibitory signals chordin, noggin and follistatin are needed to form neural plate. These inhibitory signals are created and emitted by the Spemann organiser. Cells which do not receive BMP4 signaling due to the effects of the inhibitory signals will develop into the anterior neuroectoderm cells of the neural plate. Cells which receive fibroblast growth factor (FGF) in addition to the inhibitory signals form posterior neural plate cells.

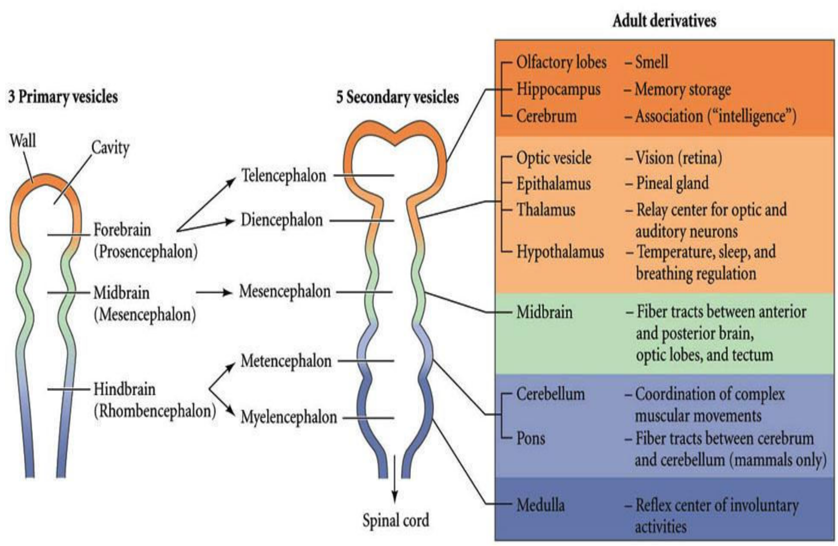


Fig. Shows early human brain development.

Four neural tube subdivisions each eventually develop into distinct regions of the central nervous system by the division of neuroepithelial cells: The prosencephalon, the mesencephalon, the rhombencephalon and the spinal cord.

- The prosencephalon further goes on to develop into the telencephalon (the forebrain or cerebrum) and the diencephalon (the optic vesicles and hypothalamus).
- The mesencephalon develops into the midbrain.
- The rhombencephalon develops into the metencephalon (the pons and cerebellum) and the myelencephalon (the medulla oblongata).

For a short time, the neural tube is open both cranially and caudally. These openings, called neuropores, close during the fourth week in humans. Improper closure of the neuropores can result in neural tube defects such as anencephaly or spina bifida.

The dorsal part of the neural tube contains the alar plate, which is associated primarily with sensation. The ventral part of the neural tube contains the basal plate, which is primarily associated with motor (i.e., muscle) control.The neural tube patterns along the dorsal-ventral axis to establish defined compartments of neural progenitor cells that lead to distinct classes of neurons. This patterning occurs early in development and results from the activity of several secreted signaling molecules. Sonic hedgehog (Shh) is a key player in patterning the ventral axis, while bone morphogenic proteins (BMPs) and Wnt family members play an important role in patterning the dorsal axis. Other factors shown to provide positional information to the neural progenitor cells include fibroblast growth factors (FGFs) and retinoic acid. Retinoic acid is required ventrally along with Shh to induce Pax6 and Olig2 during differentiation of motor neurons.

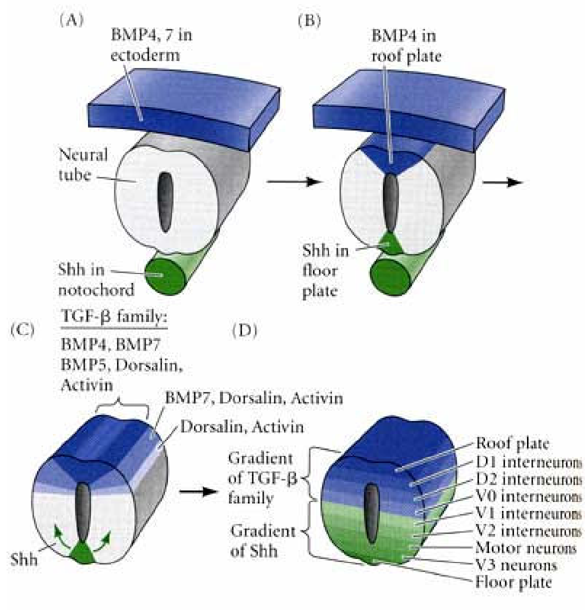


Fig. Dorsal ventral specification of the neural tube.

The human brain consists of over 10^{11} neurons associated with over 10^{12} glial cells. Those cells that remain integral components of the neural tube lining become ependymal cells. These cells can give rise to the precursors of neurons and glial cells. It is thought that the differentiation of these precursor cells is largely determined by the environmental that they enter and that at least in some cases a given ependymal cell can form both neurons and glia. In central nervous system these glial cell is called oligodendrocyte and in peripheral nervous system a glial cell type called the Schwann cell. Both are covered with myelin sheath.

Neural competence : the achaete – scute genes

In Drosophila the genes activated in the neural ectoderm that enable a cell to become a neuroblast are called the proneural genes. These genes encode the transcription factors Achaete and Scute, among others. In mammals the MASH1 gene (mammalian achaete- scute homologue) is expressed in subsets of neurons, and may influence neuronal differentiation in olfactory receptor cells as well as other cells of the central nervous system.

Signalling out neuronal precursors : the notch delta interactions

Not every ectodermal cell expressing the proneural genes becomes a neuron. Many more become glial or skin cells. The delta protein (a ligand) and the notch protein (a receptor) interact such that delta activates signal transduction in the adjacent cell through that cell’s notch proteins. The cell with slightly more delta protein on its cell surface will inhibit its neighbouring cells from becoming neurons. In flies, frogs, and chicks delta is found in those cells that will become neurons, while notch is elevated in those cells that become the glial cells. The down regulation of notch in new neurons also appears to be the same in chicks and flies.

14.9 Larval formation Post embryonic development - larva formation, metamorphosis Larval formation

A larva is a distinct juvenile form many animals undergo before metamorphosis into adults. Animals with indirect development such as insects, amphibians or cnidarians typically have a larval phase of their life cycle.

The larva's appearance is generally very different from the adult form (e.g. caterpillars and butterflies), and a larva often has unique structures and larval organs that do not occur in the adult form. A larva's diet can be considerably different from that of the adult form.

Larvae are frequently adapted to environments separate from adults. For example some larvae such as tadpoles live exclusively in aquatic environments, but as adults can live outside water as frogs. By living in distinct environments larvae may be given shelter from predators and reduce competition for resources with the adult population.

Animals in the larval stage will consume food to fuel their transition into the adult form. Some species such as barnacles are immobile as adults and use their mobile larvae form to distribute themselves.

The larvae of some species can become pubescent and not further develop into the adult form (for example in some newt). This is type of neoteny.

It is a misunderstanding that the larval form always reflects the group's evolutionary history. It could be the case but often the larval stage has evolved secondary as in insects. In these cases the larval form might differ more from the group's common origin than the adult form.

In fog hatching occurs about 2 weeks after fertilization. After hatching, the free larval stages of frog are known as tadpoles. The newly hatched tadpole is a small blackish, fish-like creature about 5-7 mm long. Body shows distinct head, trunk and tail regions.

The respiratory organs of a newly hatched tadpole are two pairs of small branched external gills. A fully formed tadpole of frog now assumes a fish-like shape, which it resembles in the body-form, mode and organs of swimming and breathing (lungs develop from pharynx so that tadpole uses both gills and lungs), and in the possession of lateral – line system of organs.

Metamorphosis

Metamorphosis is a biological process by which an animal physically develops after birth or hatching, involving a conspicuous and relatively abrupt change in the animal's body structure through cell growth and differentiation. Someinsects, fishes,amphibians,molluscs,crustaceans,cnidarians, echinoderms and tunicates u ndergo metamorphosis, which is often accompanied by a change of nutrition source or behavior. Animals can be divided into species that undergo complete metamorphosis ("holometaboly"), incomplete metamorphosis ("hemimetaboly"), or no metamorphosis ("ametaboly").

In most species of animals, embryonic development leads to a larval stage with characteristics very different from those of the adult organism. Very often, larval forms are specialized for some function, such as growth or dispersal. The pluteus larva of the sea urchin, for instance, can travel on ocean currents, whereas the adult urchin leads a sedentary existence. The caterpillar larvae of butterflies and moths are specialized for feeding, whereas their adult forms are specialized for flight and reproduction, often lacking the mouthparts necessary for eating. The division of functions between larva and adult is often remarkably distinct

Amphibian metamorphosis

During metamorphosis, developmental processes are reactivated by specific hormones, and the entire organism changes to prepare itself for its new mode of existence. These changes are not solely ones of form. In amphibian tadpoles, metamorphosis causes the developmental maturation of liver enzymes, hemoglobin, and eye pigments, as well as the remodeling of the nervous, digestive, and reproductive systems. Thus, metamorphosis is often a time of dramatic developmental change affecting the entire organism.

Morphological changes associated with metamorphosis

In amphibians, metamorphosis is generally associated with the changes that prepare an aquatic organism for a primarily terrestrial existence. In urodeles (salamanders), these changes include the resorption of the tail fin, the destruction of the external gills, and a change in skin structure. In anurans (frogs and toads), the metamorphic changes are more dramatic, and almost every organ is subject to modification. Regressive changes include the loss of the tadpole's horny teeth and internal gills, as well as the destruction of the tail. At the same time, constructive processes such as limb development and dermoid gland morphogenesis are also evident. The means of locomotion changes as the paddle tail recedes while the hindlimbs and forelimbs develop. The tadpole's cartilaginous skull is replaced by the predominantly bony skull of the frog. The horny teeth used for tearing pond plants disappear as the mouth and jaw take a new shape, and the tongue muscle develops. Meanwhile, the large intestine characteristic of herbivores shortens to suit the more carnivorous diet of the adult frog. The gills regress, and the gill arches degenerate. The lungs enlarge, and muscles and cartilage develop for pumping air in and out of the lungs. The sensory apparatus changes, too, as the lateral line system of the tadpole degenerates, and the eye and ear undergo further differentiation. The middle ear develops, as does the tympanic membrane characteristic of frog and toad outer ears. In the eye, both nictitating membranes and eyelids emerge.

When an animal changes its habitat and mode of nutrition, one would expect the nervous system to undergo dramatic changes, and it certainly does. One readily observed consequence of anuran metamorphosis is the movement of the eyes forward from their originally lateral position (Figure). The lateral eyes of the tadpole are typical of preyed-upon herbivores, whereas the frontally located eyes of the frog befit its more predatory lifestyle. To catch its prey, the frog needs to see in three dimensions. That is, it has to acquire a binocular field of vision wherein input from both eyes converges in the brain. In the tadpole, the right eye innervates the left side of the brain, and vice versa. There are no ipsilateral (same-side) projections of the retinal neurons. Thus, the anuran nervous system undergoes enormous restructuring during metamorphosis. Some neurons die, others are born, and others change their specificity.

Biochemical changes associated with metamorphosis

In addition to the obvious morphological changes, important biochemical transformations occur during metamorphosis. In tadpoles (as in freshwater fishes), the major retinal photopigment is porphyropsin. During metamorphosis, the pigment changes to rhodopsin, the characteristic photopigment of terrestrial and marine vertebrates. Tadpole hemoglobin is changed into an adult hemoglobin that binds oxygen more slowly and releases it more rapidly than does tadpole hemoglobin. The liver enzymes change also, reflecting the change in habitat. Tadpoles, like most freshwater fishes, are ammonotelic; that is, they excrete ammonia. Many adult frogs (such as the genus *Rana,* but not the more aquatic *Xenopus*) areureotelic, excreting urea, like most terrestrial vertebrates, which requires less water than excreting ammonia. During metamorphosis, the liver begins to synthesize the urea cycle enzymes necessary to create urea from carbon dioxide and ammonia.

Hormonal control of amphibian metamorphosis

The control of metamorphosis by thyroid hormones was demonstrated by Guder-natsch (1912), who discovered that tadpoles metamorphosed prematurely when fed powdered sheep thyroid gland. In a complementary study, Allen (1916)found that when he removed or destroyed the thyroid rudiment from early tadpoles (thus performing a thyroidectomy), the larvae never metamorphosed, instead becoming giant tadpoles.

The metamorphic changes of frog development are all brought about by the secretion of the hormones thyroxine (T_4) and triiodothyronine (T_3) from the thyroid during metamorphosis. It is thought that T_3 is the more important hormone, as it will cause metamorphic changes in thyroidectomized tadpoles in much lower concentrations than will T_4.

Regionally specific changes

The various organs of the body respond differently to hormonal stimulation. The same stimulus causes some tissues to degenerate while causing others to develop and differentiate. For instance, tail degeneration is clearly associated with increasing levels of thyroid hormones. The degeneration of tail structures is relatively rapid, as the bony skeleton does not extend to the tail, which is supported only by the notochord. The regression of the tail is brought about by apoptosis, and it occurs in four stages. First, protein synthesis decreases in the striated muscle cells of the tail. Next, there is an increase in concentrations of digestive enzymes within the cells. Concentrations of lysosomal proteases, RNase, DNase, collagenase, phosphatase, and glycosidases all rise in the epidermis, notochord, and nerve cord cells. Cell death is probably caused by the release of these enzymes into the cytoplasm. After cell death occurs, macrophages collect in the tail region, digesting the debris with their own proteolytic enzymes. The result is that the tail becomes a large sac of proteolytic enzymes. The major proteolytic enzymes involved appear to be collagenases and other metalloproteinases whose synthesis depends on thyroid hormones. If a metalloproteinase inhibitor (TIMP) is added to the tail, it prevents tail regression.

he response to thyroid hormones is specific to the region of the body. Tadpole head and body epidermis differentiate a new set of glands when exposed to T_3.

In the tail, however, T_3 causes the death of the epidermal cells and a tail-specific suppression of stem cell divisions that could give rise to more epidermal cells. The result is the death of the tail epidermal cells, while the head and body epidermis continues to function. These regional epidermal responses appear to be controlled by the regional specificity of the dermal mesoderm. If tail dermatome cells (mesodermal cells that generate the tail dermis) are transplanted into the trunk, the epidermis they contact will degenerate upon metamorphosis. Conversely, when trunk dermatome is transplanted into the tail, those regions of skin persist. Changing the ectoderm does not alter the regional response to thyroid hormones.

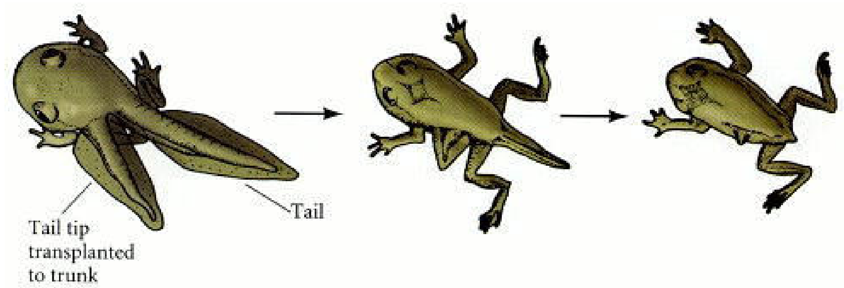


Fig. Regional specificity during frog metamorphosis. Tail tips regress even when transplanted to the trunk. Eye cups, however, remain intact even when transplanted into the regressing tail.

Organ-specific response to thyroid hormones is dramatically demonstrated by transplanting a tail tip to the trunk region or by placing an eye cup in the tail. The tail tip placed in the trunk is not protected from degeneration, but the eye retains its integrity despite the fact that it lies within the degenerating tail. Thus, the degeneration of the tail represents an organ-specific programmed cell death. Only specific tissues die when a signal is given. Such programmed cell deaths are important in molding the body. The degeneration of the human tail during week 4 of development resembles the regression of the tadpole tail.

Coordination of developmental changes

One of the major problems of metamorphosis is the coordination of developmental events. For instance, the tail should not degenerate until some other means of locomotion—the limbs—has developed, and the gills should not regress until the animal can utilize its newly developed lung muscles. The means of coordinating metamorphic events appears to be a difference among tissues and organs in their responsiveness to different amounts of hormone. This model is called the threshold concept. As the concentration of thyroid hormones gradually builds up, different events occur at different concentrations of the hormones. If tadpoles are deprived of their thyroids and are placed in a dilute solution of thyroid hormones, the only morphological effects are the shortening of the intestines and accelerated hindlimb growth. However, at higher concentrations of thyroid hormones, tail regression is seen before the hindlimbs are formed. These experiments suggest that as thyroid hormone levels gradually rise, the hindlimbs develop first and then the tail regresses. Similarly, when T_3 is given to tadpoles, it induces the earliest-forming bones at the lowest dosages and the last bones at higher dosages, mimicking the natural situation. Thus, the timing of metamorphosis appears to be regulated by the sensitivity of different tissues to thyroid hormones.

To ensure that this timing system works, two of the organs most sensitive to thyroxine are the thyroid itself and the pituitary gland, which regulates thyroid hormone production. Thyroid hormones initially create positive feedback to the pituitary gland, causing the anterior pituitary to induce the thyroid to produce more T_3 and T_4. Later, as an effect of metamorphosis, the thyroid partially degenerates, and inhibitors of thyroid hormone functions are made.

Molecular responses to thyroid hormones during metamorphosis

Thyroid hormones appear to work largely at the level of transcription, activating the transcription of some genes and repressing the transcription of others. The transcription of the genes for albumin, carbamoylphosphate synthase, adult globin, adult skin keratin, and the *Xenopus* homologue of *sonic hedgehog* is activated by thyroid hormones. The transcription of the *sonic hedgehog* gene in the intestine is particularly interesting, since it suggests that the regional patterning of the organs formed during metamorphosis might be generated by the reappearance of some of the same molecules that structured the embryo.

But these are relatively late responses to thyroid hormones. The earliest response to T_3 is the transcriptional activation of the thyroid hormone receptor (TR) genes. Thyroid hormone receptors are members of the steroid hormone receptor superfamily of transcription factors. There are two major types of T_3 receptors, TRα and TRβ. Interestingly, the mRNAs and proteins of both TRs are present at relatively low levels in the premetamorphosis tadpole and then increase before thyroid hormone is released or metamorphosis begins. The thyroid hormone receptors may bind to their specific sites on the chromatin even before thyroid hormones are present, and they are thought to repress gene transcription. When T_3 or T_4 enters the cell and binds to the chromatin-bound receptors, the hormone-receptor complex is converted from a repressor to a strong transcriptional activator. At this time, the synthesis of TRs accelerates dramatically, coinciding with the onset of metamorphosis.

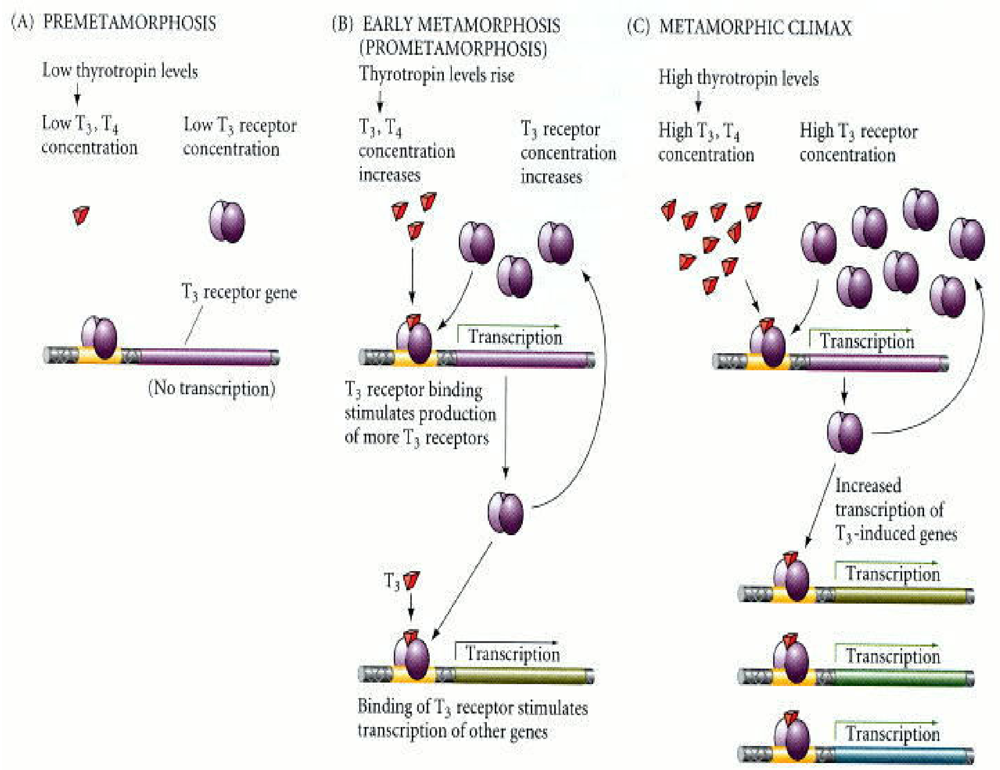


Fig. Molecular responses to thyroid hormones during metamorphosis.

The injection of exogenous T_3 causes a twofold to fivefold increase in TRα message and a 20- to 50-fold increase in the mRNA for TRβ. Thus, T_3 binds to its TR and transcribes the *TR* gene. This "autoinduction" of T_3 receptor message by T_3 may play a significant role in the acceleration of metamorphosis. The more T_3 receptors a tissue has, the more competent it should be to respond to small amounts of T_3. Thus, metamorphic climax, that time when the visible changes of metamorphosis occur rapidly, may be brought about by the enhanced production and induction of more T_3 receptors. The TR does not work alone, however, but forms a dimer with the retinoid receptor, RXR. This dimer binds thyroid hormones and can enter the nucleus to effect transcription.

The hormone prolactin has been found to inhibit the up-regulation of TRα and TRβ mRNAs. Moreover, if the up-regulation of the TR is experimentally blocked by prolactin, the tail is not resorbed, and the adult-specific keratin gene is not activated. Injections of prolactin stimulate larval growth and inhibit metamorphosis, but there is dispute as to whether this finding reflects the natural role of prolactin. We still do not know the mechanisms by which levels of thyroid hormone are regulated in the tadpole, nor do we know how the reception of thyroid hormone elicits different responses (proliferation, differentiation, cell death) in different tissues.

Metamorphosis in insects

Types of insect metamorphosis

Whereas amphibian metamorphosis is characterized by the remodeling of existing tissues, insect metamorphosis often involves the destruction of larval tissues and their replacement by an entirely different population of cells. Insects grow by molting- shedding their cuticle- and growing new cuticle as their size increases. There are three major patterns of insect development. A few insects, such as springtails and mayflies, have no larval stage and undergo direct development. These are called the ametabolous insects. These insects have a pronymph stage immediately after hatching, bearing the structures that have enabled it to get out of the egg. But after this transitory stage, the insect begins to look like a small adult; after each molt, they are bigger, but unchanged in form. Other insects, notably grasshoppers and bugs, undergo a gradual, hemimetabolous metamorphosis. After spending a very brief period of time as a pronymph (whose cuticle is often shed as the insect hatches), the insect looks like an immature adult. This immature stage is called a nymph. The rudiments of the wings, genital organs, and other adult structures are present, and these structures become more mature with each molt. At the last molt, the emerging insect is a winged and sexually mature adult.

In the holometabolous insects (flies, beetles, moths, and butterflies), there is no pronymph stage. The juvenile form that hatches from the egg is called a larva. The larva (caterpillar, grub, maggot) undergoes a series of molts as it becomes larger. The stages between these larval molts are called instars. The number of molts before becoming an adult is characteristic for the species, although environmental factors can increase or decrease the number. The instar stages grow in a stepwise fashion, each being qualitatively larger than the previous one. Finally, there is a dramatic and sudden transformation between the larval and adult stages. After the last instar stage, the larva undergoes ametamorphic molt to become a pupa. The pupa does not feed, and its energy must come from those foods it ingested while a larva. During pupation, the adult structures are formed and replace the larval structures. Eventually, an imaginal molt enables the adult ("imago") to shed the pupal case and emerge. While the larva is said to *hatch* from an egg, adults are said to eclose from the pupa.

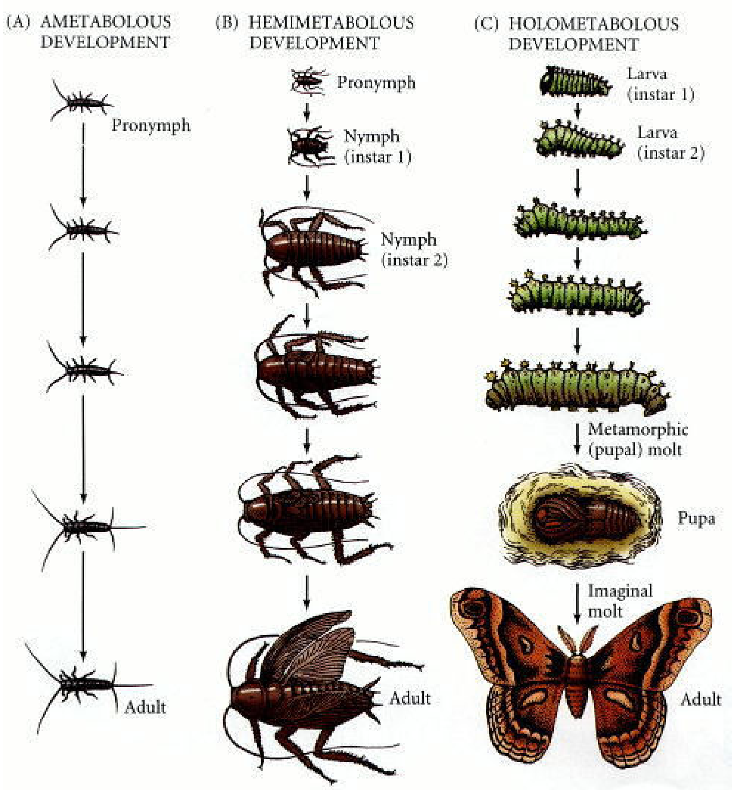


Fig. Types of insect metamorphosis.

Eversion and differentiation of the imaginal discs

In holometabolous insects, the transformation from juvenile into adult occurs within the pupal cuticle. Most of the old body of the larva is systematically destroyed by apoptosis, while new adult organs develop from undifferentiated nests of cells, the imaginal discs . Thus, within any larva, there are two distinct populations of cells: the larval cells, which are used for the functions of the juvenile insect, and the thousands of imaginal cells, which lie within the larva in clusters, awaiting the signal to differentiate.

In *Drosophila,* there are ten major pairs of imaginal discs, which construct many of the adult organs, and an unpaired genital disc, which forms the reproductive structures. The abdominal epidermis forms from a small group of imaginal cells called histoblasts, which lie in the region of the larval gut. Other nests of histoblasts located throughout the larva form the internal organs of the adult.

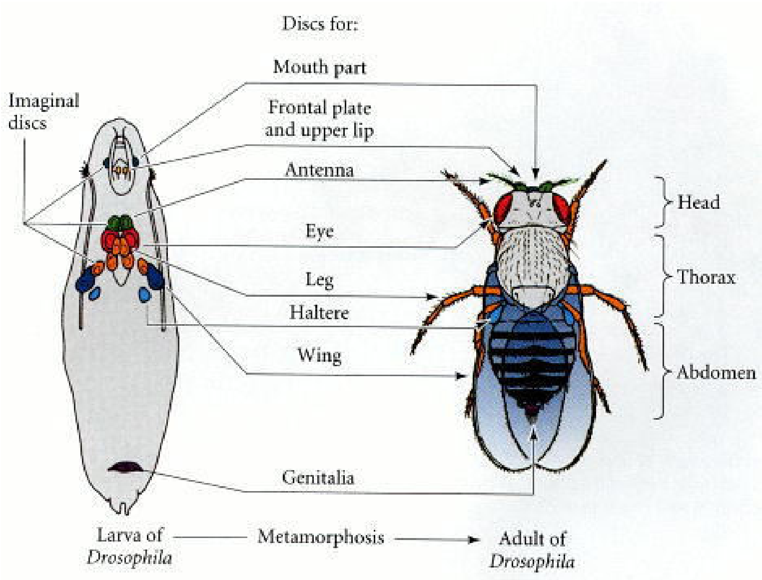


Fig. Eversion and differentiation of the imaginal discs.

Hormonal control of insect metamorphosis

Although the detailed mechanisms of insect metamorphosis differ among species, the general pattern of hormone action is very similar. Like amphibian metamorphosis, the metamorphosis of insects appears to be regulated by effector hormones, which are controlled by neurohormones in the brain. Insect molting and metamorphosis are controlled by two effector hormones: the steroid 20-hydroxyecdysoneand the lipid juvenile hormone (JH). 20-hydroxyecdysone initiates and coordinates each molt and regulates the changes in gene expression that occur during metamorphosis. Juvenile hormone prevents the ecdysone-induced changes in gene expression that are necessary for metamorphosis. Thus, its presence during a molt ensures that the result of that molt produces another instar, not a pupa or an adult.

The molting process is initiated in the brain, where neurosecretory cells release prothoracicotropic hormone (PTTH) in response to neural, hormonal, or environmental signals. PTTH is a peptide hormone with a molecular weight of approximately 40,000, and it stimulates the production of ecdysone by the prothoracic gland. This ecdysone is modified in peripheral tissues to become the active molting hormone 20-hydroxyecdysone.† Each molt is initiated by one or more pulses of 20-hydroxyecdysone. For a larval molt, the first pulse produces a small rise in the hydroxyecdysone concentration in the larval hemolymph (blood) and elicits a change in cellular commitment. A second, large pulse of hydroxyecdysone initiates the differentiation events associated with molting. The hydroxyecdysone produced by these pulses commits and stimulates the epidermal cells to synthesize enzymes that digest and recycle the components of the cuticle.

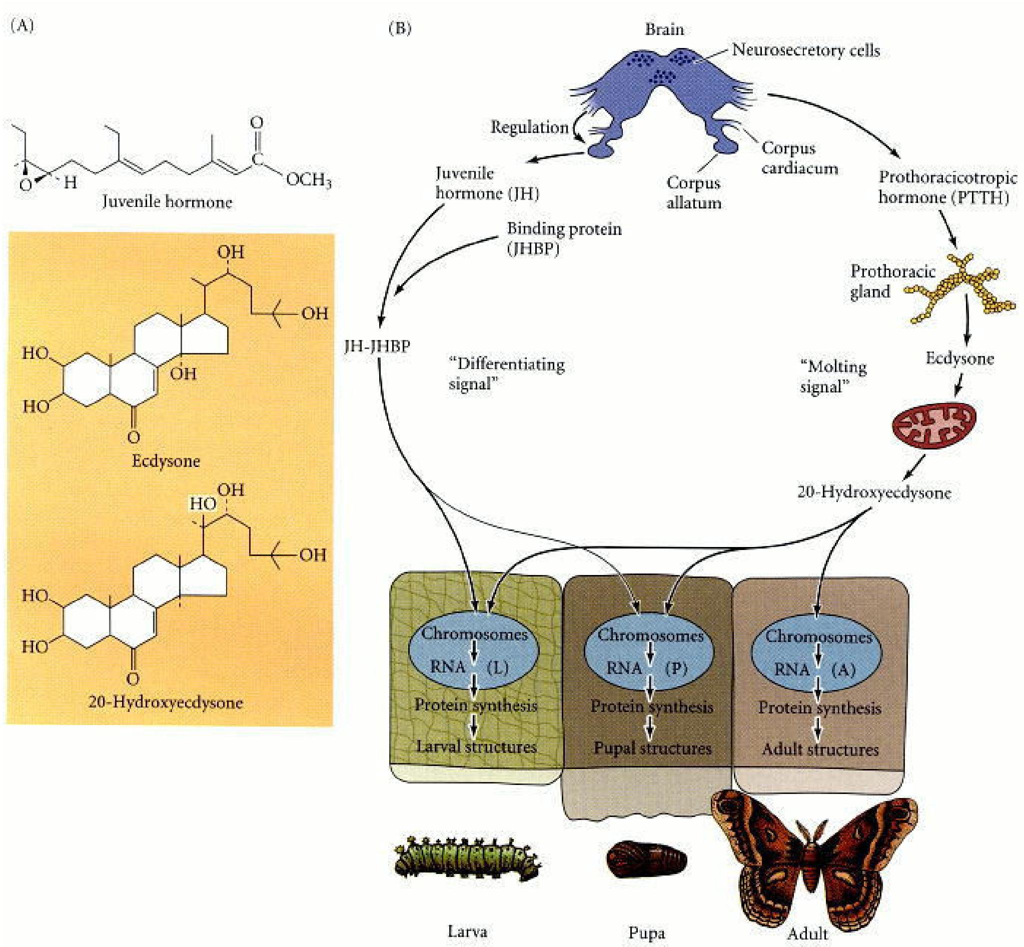


Fig. Shows hormonal control of insect metamorphosis.

Juvenile hormone is secreted by the corpora allata. The secretory cells of the corpora allata are active during larval molts but inactive during the metamorphic molt. As long as JH is present, the hydroxyecdysone-stimulated molts result in a new larval instar. In the last larval instar, however, the medial nerve from the brain to the corpora allata inhibits the gland from producing JH, and there is a simultaneous increase in the body's ability to degrade existing JH. Both these mechanisms cause JH levels to drop below a critical threshold value. This triggers the release of PTTH from the brain. PTTH, in turn, stimulates the prothoracic glands to secrete a small amount of ecdysone. The resulting hydroxyecdysone, in the absence of high levels of JH, commits the cells to pupal development. Larva-specific mRNAs are not replaced, and new mRNAs are synthesized whose protein products inhibit the transcription of the larval messages. After the second ecdysone pulse, new pupa-specific gene products are synthesized, and the subsequent molt shifts the organism from larva to pupa. It appears, then, that the first ecdysone pulse during the last larval instar triggers the processes that inactivate the larva-specific genes and prepare the pupa-specific genes to be transcribed. The second ecdysone pulse transcribes the pupa-specific genes and initiates the molt. At the imaginal molt, when ecdysone acts in the absence of juvenile hormone, the imaginal discs differentiate, and the molt gives rise to the adult.

The molecular biology of hydroxyecdysone activity

Ecdysone receptors

20-hydroxyecdysone cannot bind to DNA by itself. Like amphibian thyroid hormones, 20-hydroxyecdysone first binds to receptors. These receptors are almost identical in structure to the thyroid hormone receptors. The receptors specifically binding 20-hydroxyecdysone are called the **ecdysone receptors** (**EcR**). An EcR protein forms an active molecule by pairing with an Ultraspiracle (Usp) protein, the homologue of the amphibian RXR that helps form the thyroid hormone receptor. Although there is only one type of gene for Usp in*Drosophila,* and only one type of gene for EcR, the EcR gene transcript can be spliced in at least three different ways to form three distinct proteins. All three EcR proteins have the same domains for 20-hydroxyecdysone and DNA binding but they differ in their N-terminal domains. The type of EcR in a cell may inform the cell how to act when it receives a hormonal signal. All cells appear to have some of each type, but the strictly larval tissues and neurons that die when exposed to 20-hydroxyecdysone are characterized by their great abundance of the EcR-B1 form of the ecdysone receptor. Imaginal discs and differentiating neurons, on the other hand, show a preponderance of the EcR-A isoform. It is therefore possible that the different receptors activate different sets of genes when they bind 20-hydroxyecdysone.

Binding of 20-hydroxyecdysone to DNA

During molting and metamorphosis, certain regions of the polytene chromosomes of *Drosophila* puff out in the cells of certain organs at certain times. These chromosome puffs represent areas where DNA is being actively transcribed. Moreover, these organ-specific patterns of chromosome puffing can be reproduced by culturing larval tissue and adding hormones to the medium or by adding hydroxyecdysone to an earlier-stage larva. When 20-hydroxyecdysone is added to larval salivary glands, certain puffs are produced and others regress. The puffing is mediated by the binding of hydroxyecdysone at specific places on the chromosomes; fluorescent antibodies against hydroxyecdysone find this hormone localized to the regions of the genome that are sensitive to it.

Hydroxyecdysone-regulated chromosome puffs occurring during the late stages of the third-instar larva (as it prepares to form the pupa) can be divided into three categories: "early" puffs that hydroxyecdysone causes to regress; "early" puffs that hydroxyecdysone induces rapidly; and "late" puffs that are first seen several hours after hydroxyecdysone stimulation. For example, in the larval salivary gland, about six puffs emerge within a few minutes of hydroxyecdysone treatment. No new protein has to be made in order for these puffs to be induced. A much larger set of genes are induced later in development, and these genes do need protein synthesis to become transcribed. Ashburner (1974, 1990) hypothesized that the "early" genes make a protein product that is essential for the activation of the "late" genes and that, moreover, this protein itself turns off the transcription of the early genes. These insights have been confirmed by molecular analyses. The three early puffs include the genes for EcR and two other transcription factors, BR-C and E74B.

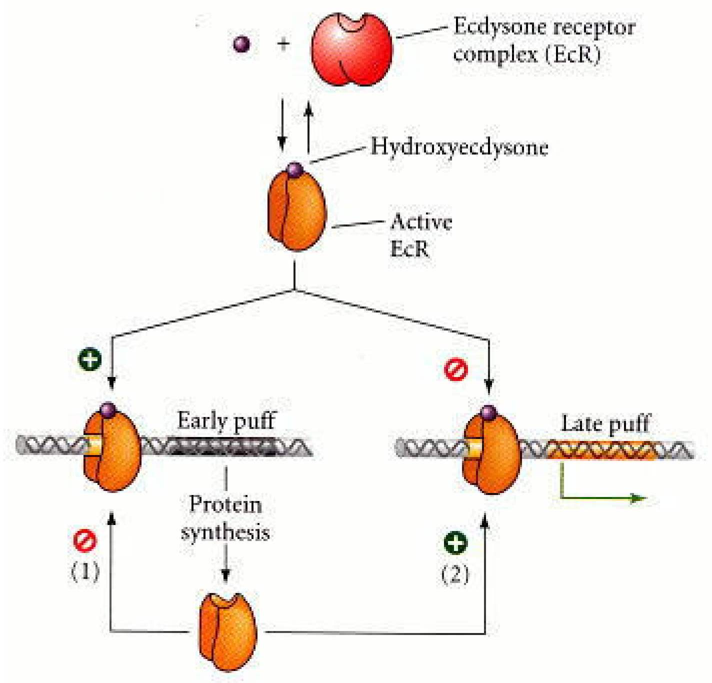


Fig. Binding of hydroxyecdysone to DNA.

he *broad-complex* (*BR-C*) gene is particularly interesting. Like the ecdysone receptor gene, the *BR-C* gene can generate several different transcription factor proteins through differentially initiated and spliced messages. It appears that the variants of the ecdysone receptor may signal particular variants of the BR-C protein to be synthesized. Organs such as the larval salivary gland that are destined for death during metamorphosis express the Z1 isoform; imaginal discs destined for cell differentiation express the Z2 isoform; and the central nervous system (which undergoes marked remodeling during metamorphosis) expresses all isoforms, with Z3 predominating.

In addition to the restricted activities of the different isoforms of BR-C, there appear to be common processes that all of the isoforms accomplish. Restifo and Wilson (1998) provided evidence that these common functions are prevented by juvenile hormone. Deletions of the *BR-C* gene lead to faulty muscle development, retention of larval structures that would normally degenerate, abnormal nervous system morphology, and eventually the death of the larva. This syndrome is very similar to that induced by adding excess JH to *Cecropia* silkworm larvae or by adding juvenile hormone analogues to *Drosophila.* Thus, it appears that juvenile hormone prevents ecdysone-inducible gene expression by interfering with the BR-C proteins.

The BR-C proteins are themselves transcription factors, and their targets remain to be identified. However, we are beginning to get a glimpse at the molecular level of one of the most basic areas of all developmental biology- the transformation of a larva into a fly, butterfly, or moth.

14.10 Homeobox concept in different phylogenetic groups

A homeobox is a DNA sequence, around 180 base pairs long, found within genes that are involved in the regulation of patterns of anatomical development (morphogenesis) in animals, fungi and plants. These genes encode homeodomain protein products that are transcription factors sharing a characteristic protein fold structure that binds DNA.

The main interest in this set of genes stems from their unique behaviour. They are typically found in an organized cluster. The linear order of the genes within a cluster is directly correlated to the order of the regions they affect as well as the timing in which they are affected. This phenomenon is called colinearity. Due to this linear relationship, changes in the gene cluster due to mutations generally result in similar changes in the affected regions.

Molecular evidence shows that some limited number of Hox genes have existed in the Cnidaria since before the earliest true Bilatera, making these genes pre-Paleozoic.Homeobox genes have even been found in fungi, for example the unicellular yeasts, and in plants.

Biological function

Through the DNA-recognition properties of the homeodomain, homeoproteins are believed to regulate the expression of targeted genes and direct the formation of many body structures during early embryonic development. They are interesting from both a developmental and evolutionary perspective since their sequences are highly conserved and shared across an enormously wide array of living taxa.

Many homeodomain proteins induce cellular differentiation by initiating the cascades of coregulated genes required to produce individual tissues and organs. Other proteins in the family, such as NANOG are involved in maintaining pluripotency. Homeobox genes are critical in the establishment of body axes during embryogenesis.

The homeobox domain was first identified in a number of *Drosophila* homeotic and segmentation proteins, but is now known to be well-conserved in many other animals, including vertebrates.The discovery of the first homeobox in eukaryotes in the early 1980s can be attributed to a group of scientists working on *Drosophila*, headed by Walter Jakob Gehring. Gehring was interested in the dramatic developmental effects associated with the gene *Antennapedia* (*Antp*), in which a head segment that normally would carry a pair of antennae develops into a body segment with a pair of legs. Several types of duplication mutations, such as *Bithorax* (*BX-C*) and *fushi tarazu* (ftz), led Gehring to believe that duplication mutations in regulatory genes could manifest as either partial or complete segmental transformations. Using existing methodologies for finding chromosomal homologies, Gehring did a chromosomal search using the *Antp* mutant as well as the *BX-C* mutant to see how if there were copies of these genes in the *Drosophila* genome. He found many. His results confirmed Edward B. Lewis's postulations in the late 1970s of collinear tandem gene duplications. This encouraged him to hypothesize, with several of his closest peers, that these mutations are actually copies of the control genes that specify unique identities for the segments in which they appear.

Specific members of the Hox family have been implicated in vascular remodeling, angiogenesis, and disease by orchestrating changes in matrix degradation, integrins, and components of the ECM. HoxA5 is implicated in atherosclerosis. HoxD3 and HoxB3 are proinvasive, angiogenic genes that upregulate b3 and a5 integrins and Efna1 in ECs, respectively. HoxA3 induces endothelial cell (EC) migration by upregulating MMP14 and uPAR. Conversely, HoxD10 and HoxA5 have the opposite effect of suppressing EC migration and angiogenesis, and stabilizing adherens junctions by upregulating TIMP1/downregulating uPAR and MMP14, and by upregulating Tsp2/downregulating VEGFR2, Efna1, Hif1alpha and COX-2, respectively. HoxA5 also upregulates the tumor suppressor p53 and Akt1 by downregulation of PTEN.Suppression of HoxA5 has been shown to attenuate hemangioma growth. HoxA5 has far-reaching effects on gene expression, causing ~300 genes to become upregulated upon its induction in breast cancer cell lines. HoxA5 protein transduction domain overexpression prevents inflammation shown by inhibition of TNFalpha-inducible monocyte binding to HUVECs.

Since Gehring's discovery in the mid-1980s, more attention has been directed towards a growing area of biological study called evolutionary developmental biology or evo-devo for short. The scientists that comprise this group are generally focused on connecting the gap between shared evolutionary ontology and developmental biology. Based on an increasing effort from this wide array of biological disciplines, most of the Antp homeobox genes in *Drosophila*, as well as many others, have been located in vertebrates and invertebrates alike, including mice, chickens, humans, and even sea urchins. These discoveries have since led scientists to poke and prod at the functional role of these genes in determining the body plan during early embryogenesis.

Homeobox genes, since their discovery, have become significant to many different fields of biology. Using gene duplication technology to probe for homologous sequences, geneticists and developmental biologists have discovered an evolutionary pattern of what seems to be paralogous gene duplication followed by specification. That is, a regulatory gene is duplicated and then, because its current function is somewhat redundant, it becomes specialized through natural selection to perform a new function. The developmental significance of such duplications manifests in the constrained co-linearity between the timing of activation in development and its location on the chromosome.

Subsequent studies have shown that certain clusters of homeotic genes, such as the *Antp* cluster in *Drosophila* and its homologous cluster, called *HoxA-D* in vertebrates, are responsible for anterior-posterior specification of body segments as well as being functionally tied to limb generation in mammals, thus giving some theoretical insight into the shared evolutionary history of even the most diverse animals.

The evolutionary origins of the dominant Antennapedia family of homeobox genes i.e., the hypothetical common ancestor of all the *Antp* mutants—can be traced back to the origin of multicellularity, approximately one billion years ago. This ancestral homeobox gene has been given the title of "ProtoHox" or "Proto-ANTP" since it is inferred that it gave rise, via a series of duplication events, to three more homeobox clusters known as Hox, ParaHox, and NK. Because each sub-cluster is predominantly expressed in one of the three germ layers: ectoderm, endoderm, or mesoderm—it has been hypothesized that each duplication event marked the emergence of one of these germ layers. The most notable byproduct of these events is the creation of novel morphological characteristics due to paralogous duplications within each of the sub-clusters themselves. For instance, within the *Hox* sub-cluster in mammals, there are four more sub-cluster duplications, the A through D clusters, each of which becomes responsible for a portion of axial body plan specification as well as limb development. This trend of hierarchical diversification of regulatory genetics in body plan diversification has inspired an entirely new way of viewing and rooting phylogenies for most metazoans.

Attempts to root the phylogenetic tree of the Proto-ANTP result in a few paradoxes. For instance, one can extrapolate that bilateral symmetry appears to have arisen before the radial symmetry of most cnidarians. This suggests that primitive cnidarians possibly had bilateral origins and three germ layers. Another interesting paradox is that of the co-linearity constraints in Hox and ParaHox gene clusters. In many of the model organisms—most of which share common characteristics of short life spans, rapid development, and easy handling—the co-linearity of Hox and ParaHox clusters tends to be more dispersed throughout the genome. It has been hypothesized that because of rapid embryological development, the inherent need for brevity has surpassed the evolutionary constraints of co-linearity. Lastly, the NK cluster, identified originally in *Drosophila* and later in vertebrates, appears to be dispersed and heavily derived throughout most vertebrate genomes. It remains largely intact in *Drosophila* and its phylogenetic neighbors. This suggests that the evolution of mesoderm characteristics in deuterostomes, such as vertebrates, is highly derived but shares a common ancestor with all protostomes, such as *Drosophila*, before the protostome-deuterostome split.

Homeobox gene interactions become exponentially complex as the multidimensional nature of gene regulatory networks is explored. However, it has given rise to an entirely new perspective on developmental biology and molecular genomics. The notion that genes turn on and off at hierarchical developmental levels has spawned years of research into the processes of these networks. The resulting research from such ventures has yielded tremendous potential for useful applications.

14.11 Summary

- Morphogenesis is the biological process that causes an organism to develop its shape.
- In animal development, organogenesis is the process by which the ectoderm,endoderm, and mesoderm develop into the internal organs of the organism.
- One of the best understood examples of pattern formation is the patterning along the future head to tail (antero-posterior) axis of the fruit fly *Drosophila melanogaster*. There are three fundamental types of genes that give way to the developmental structure of the fly: maternal effect genes, segmentation genes, and homeotic genes.
- Pattern formation is the development of a body according to a specific and planned spatial arrangement. The vertebrate limb is an extremely complex organ with an asymmetrical arrangement of parts. There are three major axes to consider one of which is the proximal (close) to distal (far) axis. The bones of the limb are it wing, foot, hand or flipper consist of a proximal stylopod (humerus/femur) adjacent to the body wall, a zeugopod (radius-ulna/tibia-fibula) in the middle region, and a distal autopod (carpals-fingers/tarsals-toes).
- Neurulation refers to the folding process in vertebrate embryos, which includes the transformation of the neural plate into the neural tube. The embryo at this stage is termed the neurula.
- Metamorphosis is a biological process by which an animal physically develops after birth or hatching, involving a conspicuous and relatively abrupt change in the animal's body structure through cell growth and differentiation.

- The metamorphic changes of frog development are all brought about by the secretion of the hormones thyroxine (T_4) and triiodothyronine (T_3) from the thyroid during metamorphosis.
- Insects are three major patterns of development i.e. ametabolous, hemimetabolous and holometabolous.
- Insect molting and metamorphosis are controlled by two effector hormones: the steroid 20-hydroxyecdysoneand the lipid juvenile hormone (JH).
- A homeobox is a DNA sequence, around 180 base pairs long, found within genes that are involved in the regulation of patterns of anatomical development (morphogenesis) in animals, fungi and plants. These genes encode homeodomain protein products that are transcription factors sharing a characteristic protein fold structure that binds DNA.

14.12 Model Examination Questions

Section (A):Very Short Answer type Questions

1. What is morphogenesis?
2. Which genes are responsible for Anterior posterior axis patterning in Drosophila?
3. Define organogenesis?
4. Define regeneration?
5. What is metamorphosis?
6. Give any two examples of gap genes?
7. How many types of insect metamorphosis?
8. Which hormones are responsible for metamorphosis in insects and amphibians?
9. Which gene is responsible for eye morphogenesis in vertebrates?
10. Define morphallaxis?

Section (B):Short Answer type Questions

1. Write short notes on:
    a) Homeobox concept in different phylogenetic groups
    b) Types of insect metamorphosis

2. What is regeneration? Describe its different types and regeneration of limb of newt?
3. Explain Vulva formation in *Caenorhabditis elegans?*
4. Write short notes on :
   a) Maternal effect genes
   b) Hormonal control of amphibian metamorphosis

Section(C):Long Answer Type Questions

1. Describe the limb development in vertebrates?
2. Give an detail account on Cell aggregation and differentiation in *Dictyostelium?*
3. Write short notes on:
   a) Metamorphosis in insect and its hormonal control
   b) Differentiation of neurons
4. Explain in detail Axis and Pattern Formation in Drosophila?
5. Write short notes on:
   a) Axis and pattern formation in amphibians
   b) Eye lens induction in vertebrates

14.13 References

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Unit - 15

Environmental Regulation

Structure of the Unit

15.1 Objectives

After going through the Unit the learner will be able to understand the effect of enviornmrnt on the development of an animal-the cues and effects. The changing evolution through the development modularity has been explained and the various constraints in development have been discussed .At the last the various methods of developing new cell types have been incorporated to acquaint with the student with the basic evolutionary mystery. The main objective of this Unit is to summarize the importance of environment in the development of the animal and help the student know that it is not just the genes which determines the animal development but surroundings also play a pivotal role in deciding the fate of the development and the line of evolution. It also enables the animal to adapt and survive unfavorable conditions.

15.1Introduction:The environment on the surface of the earth is suited to and largely responsible for the existence of living organisms. After an organism come into existence, it strives to live in harmony with its immediate environment. An organism is a "system of activities" which devotes its enegies primarily to three functions:- (i)capturing energy for and releasing energy from its own system.(ii) protecting its system from injury.(iii)producing other systems of activities similar to itself. If possible an organism reacts with its environment in such a way that its system continues to exist and carry on its three primary functions. It is limited in its responses to a particular behavior pattern , inherited from the system from which it came, but in general it reacts in such a way towards it environment that it selects by trial the optimum conditions for its own existence .In other words, an organism generally responds in an adaptive way and selects the best environment that it can. If the behavior pattern of certain systems, similar or dissimilar, are well suited to a particular environment such system are often successful. They may take possession of the environment, perhaps exterminating other systems, nd thus demonstrating their fitness constitute what ecologist call a climax formation. Every organism in such a group must remain in a system of activities and must make continual physiological adjustments to keep in harmony with the environment or it cannot continue to exist.

15.2 Environmental Cues and effects on the development of animals

15.2.1 Larval settlement

The inclusion of environmental cues into normal development occurs during the settling of marine larvae. These cues may not be constant, but they need to be part of the environment if further development is to occur. A free-swimming marine larva often needs to settle near a source of food or on a firm substrate on which it can metamorphose. Thus, if prey or substrates give off soluble molecules, these molecules can be used by the larvae as cues to settle and begin metamorphosis. Among the molluscs, there are often very specific cues for settlement. In some cases, the prey supply the cues, while in other cases the substrate gives off molecules used by the larvae to initiate settlement.

Specific settlement substrates of molluscan larvae.

One of the best studied cases of larval settlement is that of the red abalone, *Haliotis rufescens.* Its larvae only settle when they physically contact coralline red algae. A brief contact is all that is required for the competent larvae to stop swimming and begin metamorphosis. The chemical agent responsible for this change has not yet been isolated, but a receptor that recognizes an algal peptide induces metamorphosis in competent larvae. Larvae that are not competent to begin metamorphosis do not appear to have this receptor. The receptor is thought to be linked to a G protein similar to those found in vertebrates, and the activation of this G protein may be necessary for inducing larval settlement and metamorphosis.

15.2.2Blood meals

In many mosquitoes, egg production is triggered by a blood meal. Only female mosquitoes bite, and prior to a blood meal they make no vitellogenin yolk protein. In *Aedes aegypti,* the digested products of the blood meal stimulate the brain to secrete egg development neurosecretory hormone (EDNH, also known as ovarian ecdysteroidogenic hormone, or OEH). This hormone stimulates the ovary to make ecdysteroids, which instruct the fat body cells to make vitellogenin for the oocytes. Vitellogenin is critical for egg production. Thus, without the blood meal, there is no vitellogenin and no eggs.

In the blood-sucking bug *Rhodinus prolixus,* adult females produce a new batch of eggs each time they drink blood. This blood meal serves two functions. Blood proteins from the mammalian host supply the amino acids needed for vitellogenin synthesis, and the physical stretching of the abdomen by the blood initiates the endocrine stimuli that activates juvenile hormone secretion by the corpora allata. JH stimulates vitellogenin synthesis in the ovary and fat body. Moreover, a single large blood meal induces the molt. If this bug takes many small meals, it will survive, but it will not molt or grow. In these instances, mammals provide the environmental cues for part of the insect's development.

15.2.3 Developmental symbiosis

In some of the above examples, the development of one individual is made possible by the presence of another individual of a different species. In some organisms, this relationship has become symbiotic. In these cases, the symbionts become so tightly integrated into the host organism that the host cannot develop without them. The adult squid *Euprymna scolopes* is equipped with a light organ composed of sacs containing the luminous bacteria *Vibrio fischeri.* The juvenile squid, however, does not contain these light-emitting symbionts; nor does it have a structure to house them. Rather, the squid acquires the bacteria from the seawater pumped through its mantle cavity. The bacteria bind to a ciliated epithelium that extends into this cavity. The bacteria induce the apoptotic death of these epithelial cells, their replacement by a nonciliated epithelium, and the differentiation of the surrounding epithelial cells into storage sacs for the bacteria.

An even tighter link between morphogenesis and symbiosis is exemplified by the leafhopper *Euscelis incisus.* Here, the symbiosis occurs within the egg. Symbiotic bacteria are found within the egg cytoplasm and are transferred through the generations, just like mitochondria. These bacteria have become so specialized that they can multiply only inside the leafhopper's cytoplasm, and the host has become so dependent on the bacteria that it cannot complete embryogenesis without them. In fact, it is thought that the bacterial symbionts are essential for the formation of the embryonic gut. If the bacteria are surgically or metabolically removed from the eggs (by feeding antibiotics to larvae or adults), these symbiont-free oocytes develop into embryos that lack an abdomen.

Predictable Environmental Differences as Cues for Development

If the environment contains predictable components (such as gravity) or predictable changes (such as seasons), these can become part of the development of the organism. The use of temperature and daylight length is used by numerous species to adjust their development to a changing environment. The stresses of gravitational pressure also play a role in the development of some organisms.

15.2.4 Seasonality and sex in aphids

Several species of aphids have a fascinating life cycle wherein an egg hatched in the spring gives rise to several generations of parthenogenetically (asexually) reproducing females. During the autumn, however, a particular type of female is produced whose eggs can give rise to both males and sexual females. These sexual forms mate, and their eggs are able to survive the winter. When the overwintering eggs hatch, each one gives rise to an asexual female.

Some of the mysteries of this type of development were solved in 1909 by Thomas Hunt Morgan (before he started working on fruit flies). Morgan analyzed the chromosomes of the hickory aphid through several generations. He found that the diploid number of the female aphids is 12. In parthenogenetically reproducing females, only one polar body is extruded from the developing ovum during oogenesis, so the diploid number of 12 is retained in the egg. This egg develops parthenogenetically, without being fertilized. In the females that give rise to eggs that become male or female, a modification of oogenesis occurs. In the female-producing eggs, 6 chromosome pairs enter the sole polar body; the diploid number of 12 is thereby retained. In male-producing eggs, however, an extra chromosome pair enters the polar body. The male diploid number is thus 10. These males and females are sexual and produce gametes by complete meiotic divisions. The females produce oocytes with a haploid set of 6 chromosomes. The males, however, divide their 10 chromosomes to produce some sperm with a haploid number of 4 and other sperm with a haploid number of 6. The sperm with 4 chromosomes degenerate. The sperm with 6 chromosomes fertilize the eggs with their 6 chromosomes to restore the diploid chromosome number 12. These eggs overwinter, and when they hatch in the spring, females emerge.

Chromosomal changes during the life cycle of the hickory aphid. Fall weather induces the production of males and females, which mate to produce the overwintering egg.

Morgan solved one riddle. The riddle of how the autumn weather regulates whether the female reproduces sexually or parthenogenetically, however, remains unsolved. Similarly, we do not know what regulates whether the diploid oocyte gives rise to male- or female-producing eggs. Moreover, the same environmental factors are used differently by other aphid species shows another type of life cycle found in aphids, involving an alternation of sexual and asexual generations. In *Megoura viciae,* temperature determines the sex early in development (with extreme temperatures favoring the production of females). In female development, day length and temperature determine whether the female will reproduce sexually or parthenogenetically, and a combination of temperature and population density determine whether she will be winged or wingless. It appears that juvenile hormone controls the parthenogenetic/sexual switch (the addition of JH to adults producing sexual offspring causes them to have parthenogenetic offspring) and inhibits the formation of wings. But it is not known how the environmental changes become transformed into titers of JH, or how the autumn weather (or perhaps declining hours of sunlight) causes the differential movement of chromosomes into the polar body.

15.3 Complex Environmental effects on development

15.3.1 Diapause

Many species of insects have evolved a strategy called **diapause**. Diapause is a suspension of development that can occur at the embryonic, larval, pupal, or adult stage, depending on the species. The overwintering eggs of the hickory aphid provide an example of this strategy. In some species, diapause is facultative and occurs only when induced by environmental conditions; in other species, diapause has become an obligatory part of the life cycle. The latter is often seen in temperate-zone insects, in which diapause is induced by changes in the photoperiod (the relative lengths of day and night). The day length at which 50 percent of the population has entered diapause is called the critical day length, and this usually occurs quite suddenly. The critical day length is a genetically determined property (Danilevskii 1965;Tauber et al. 1986).

Diapause is not a physiological response brought about by harsh conditions. Rather, it is brought about by token stimuli that presage a change in the environment, beginning before the severe conditions actually arise. Diapause is especially important for temperate-zone insects, enabling them to survive the winter. The silkworm moth *Bombyx mori* overwinters as an embryo, entering diapause just before segmentation. The gypsy moth *Lymantia dispar* initiates its diapause as a fully formed larva, ready to hatch as soon as diapause ends.

Phenotypic plasticity:Polyphenism and Reaction Norms

The ability of an individual to express one phenotype under one set of circumstances and another phenotype under another set is called **phenotypic plasticity**.There are two main types of phenotypic plasticity: polyphenism and reaction norms. **Polyphenism** refers to discontinuous phenotypes elicited by the environment. Migratory locusts, for instance, exist in two mutually exclusive forms: a short-winged, uniformly colored solitary phase and a long-winged, brightly colored gregarious phase. Cues in the environment (mainly population density) determine which morphology a young locust will take. Similarly, the nymphs of planthoppers can develop in two ways, depending on their environment. High population densities and the presence of certain plant communities lead to the production of migratory insects, in which the third thoracic segment produces a large hindwing. Low population densities and other food plants lead to the development of flightless planthoppers, with the third thoracic segment developing into a haltere-like vestigial wing. The seasonal coat color changes in arctic animals are another example of polyphenism.

In other cases, the genome encodes a range of potential phenotypes, and the environment selects the phenotype that is usually the most adaptive. For instance, constant and intense labor can make our muscles grow larger; but there is a genetically defined limit to how much hypertrophy is possible. Similarly, the microhabitat of a young salamander can cause its color to change (again, within genetically defined limits). This continuous range of phenotypes expressed by a single genotype across a range of environmental conditions is called the **reaction norm** . The reaction norm is thus a property of the genome and can also be selected. Different genotypes are expected to differ in the direction and amount of plasticity that they are able to express.

15.3.2Nutritional polyphenism

Not all polyphenisms are controlled by the seasons. In bees, the size of the female larva at its metamorphic molt determines whether the individual is to be a worker or a queen. A larva fed nutrient-rich "royal jelly" retains the activity of her corpora allata during her last instar stage. The juvenile hormone secreted by these organs delays pupation, allowing the resulting bee to emerge larger and (in some species) more specialized in her anatomy. The JH level of larvae destined to become queens is 25 times that of larvae destined to become workers, and application of JH onto worker larvae can transform them into queens as well.

Similarly, ant colonies are predominantly female, and the females can be extremely polymorphic. The two major types of females are the worker and the gyne. The **gyne** is a potential queen. In more specialized species, a larger worker, the soldier, is also seen. In *Pheidole bicarinata,* these castes are determined by the levels of JH in the developing larvae. Larvae given protein-rich food have an elevated JH titer, which causes an abrupt developmental switch that "reprograms" the size at which the larvae will begin metamorphosis. This causes a large and discontinuous size difference between the gyne, soldier, and worker castes. This reprogramming also involves changes in gene activity, since the cuticular proteins of the workers and soldiers are different.

15.3.3Environment-dependent sex determination

There are many species in which the environment determines whether an individual is to be male or female. The temperature-dependence of sex determination in fishes and reptiles has provided the best studied cases. This type of environmental sex determination has advantages and disadvantages. One advantage is that it probably gives the species the benefits of sexual reproduction without tying the species to a 1:1 sex ratio. In crocodiles, in which temperature extremes produce females while moderate temperatures produce males, the sex ratio may be as great as 10 females to each male. The major disadvantage of temperature-dependent sex determination may be its narrowing of the temperature limits within which a species can exist. This means that thermal pollution (either locally or due to global warming) could conceivably eliminate a species in a given area. speculate that dinosaurs may have had temperature-dependent sex determination and that their sudden demise may have been caused by a slight change in temperature that created conditions wherein only males or only females hatched from their eggs.

The environmental sex determination would be adaptive in certain habitats characterized by patchiness—a habitat having some regions where it is more advantageous to be male and other regions where it is more advantageous to be female. In certain fishes, females benefit from being larger, since size translates into higher fecundity. If you are a female Atlantic silverside (*Menidia menidia*), it is advantageous to be born early in the breeding season, which allows you a longer feeding season and thus would allow you to grow larger. In the males, size is of no importance. Conover and Heins showed that in the southern range of *Menidia,* females are indeed born early in the breeding season. Temperature appears to play a major role in this pattern. However, in the northern reaches of its range, the species shows no environmental sex determination. Rather, a 1:1 ratio is generated at all temperatures. The researchers speculated that the more northern populations have a very short feeding season, so there is no advantage for a female to be born earlier. Thus, this species of fish has environmental sex determination in those regions where it is adaptive and genotypic sex determination in those regions where it is not. Here again, one sees that the environment can induce sexual phenotype, or sexual phenotype can be a property of the genome, as it is with most mammals.

Temperature isn't the only environmental factor that can affect sex determination in fish. The sex of the blue-headed wrasse, a Panamanian reef fish, depends on the other fish it encounters. If the wrasse larva reaches a reef where a male lives with many females, it develops into a female. When the male dies, one of the females (usually the largest) becomes a male. Within a day, its ovaries shrink and its testes grow. If the same wrasse larva had reached a reef that had no males or that had territory undefended by a male, it would have developed into a male wrasse.

15.3.4Polyphenisms for alternative conditions

Most studies of adaptations concern the roles that adult structures play in enabling the individual to survive in otherwise precarious or hostile environments. However, the developing animal, too, has to survive in its habitat, and its development must adapt to the conditions of its existence.

The spadefoot toad, *Scaphiopus couchii,* has a remarkable strategy for coping with a very harsh environment. The toads are called out from hibernation by the thunder that accompanies the first spring storm in the Sonoran desert. (Unfortunately, motorcycles produce the same sounds, causing these toads to come out from hibernation and die in the scorching Arizona sunlight.) The toads breed in temporary ponds formed by the rain, and the embryos develop quickly into larvae. After the larvae metamorphose, the young toads return to the desert, burrowing into the sand until the next year's storms bring them out.

Desert ponds are ephemeral pools that can either dry up quickly or persist, depending on the initial depth and the frequency of the rainfall. One might envision two alternative scenarios confronting a tadpole in such a pond: either (1) the pond persists until you have time to metamorphose and you live, or (2) the pond dries up before your metamorphosis is complete, and you die. These toads (and several other amphibians), however, have evolved a third alternative. The time of metamorphosis is controlled by the pond. If the pond persists at a viable level, development continues at its normal rate, and the algae-eating tadpoles eventually develop into juvenile spadefoot toads. However, if the pond is drying out and getting smaller, overcrowding occurs, and some of the tadpoles embark on an alternative developmental pathway. They develop a wider mouth and powerful jaw muscles, which enable them to eat (among other things) other *Scaphiopus* tadpole. These carnivorous tadpoles metamorphose quickly, albeit into a smaller version of the juvenile spadefoot toad. But they survive while other *Scaphiopus* tadpoles perish, either from desiccation or ingestion by their pondmates.

Such phenotypic plasticity is also seen in echinoderm larvae. When food is scarce, the ciliated arms of the pluteus larva grow longer and increase the ability of the larva to obtain food. But this is done at a cost to the adult rudiment growing within the larva, and it takes longer for those long-armed plutei (even if they can acquire food) to metamorphose.

Phenotypic plasticity gives an individual the ability to respond to different environmental conditions. Different phenotypes are more fit in different environments. In the spadefoot toad, the faster-developing carnivorous form is more fit in quickly drying ponds, but the slower-developing tadpoles (which develop into larger, more robust toads) are more fit in wetter conditions. There is a “trade-off” in evolving this phenotypic plasticity, but it helps ensure that some animals will survive, whichever condition prevails at a given time.

15.3.5 Predator induced Defenses

One survival strategy for coping with a harsh environment is for an animal to evolve the ability to develop a new structure when confronted by a particular predator. In such cases, the development of the animal is changed by chemicals released by the predator, enabling the embryos or juveniles to better escape those same predators. This is sometimes called **predator-induced defense**, or **predator-induced polyphenism**.

To demonstrate predator-induced polyphenism, one has to show that the phenotypic change is caused by the predator (usually by soluble chemicals released by the predator) and that the phenotypic modification increases the fitness of its bearers when the predator is present. For instance, several rotifer species will alter their morphology when they develop in pond water in which their predators were cultured. The predatory rotifer *Asplanchna* releases into its water a soluble compound that induces the eggs of a prey rotifer species, *Keratella slacki,* to develop into individuals with slightly larger bodies, but with anterior spines 130 percent longer than they would otherwise be. These changes make them more difficult to eat. The snail *Thais lamellosa* develops a thickened shell and a "tooth" in its aperture when exposed to the effluent of the crab species that preys on it. In a mixed population, crabs will not attack the thicker snails until more than 50 percent of the normal snails are devoured

The predator-induced polyphenism of the parthenogenetic water flea *Daphnia* is beneficial not only to itself, but also to its offspring. When *Daphnia cucullata* encounter the predatory larvae of the fly *Chaeoborus,* their "helmets" grows to twice their normal size. This inhibits their being eaten by the fly larvae. This same helmet induction occurs if the*Daphnia* are exposed to extracts of water in which the fly larvae had been swimming . Chemicals that are released by a predator and can induce defenses in the prey are called **kairomones**. It is possible that the kairomone regulates gene expression both in the adult and in the developing embryos. We still do not know how *Daphnia* evolved the ability to make receptors that bind the kairomone or to utilize the kairomone to generate an adaptive morphological change.

15.4 Changing Evolution through development modularity

Modularity refers to the ability of a system to organize discrete, individual units that can overall increase the efficiency of network activity and, in a biological sense, facilitates selective forces upon the network. It has been observed in all model systems and can be studied at nearly every scale of organization (molecular interactions all the way up to the whole organism).

15.4.1Evolution of Modularity

The exact evolutionary origins of biological modularity has been debated for over the past decade. In the mid 90's, Günter Wagner argued that modularity could have arisen and been maintained through the complex interaction of four potential evolutionary modes of action:

[1] Selection for the rate of adaptation: If different complexes evolve at different rates, then those evolving more quickly reach fixation in a population faster than other complexes. Thus, common evolutionary rates could be

canalizing certain proteins to evolve together while preventing other genes from being co-opted unless there is a shift in evolutionary rate.

[2] Constructional selection: This refers to the ability of a duplicated gene to be maintained due to the amount of connections it has (also termed pleiotropy). In fact, there is evidence that following whole genome duplication or duplication at a single locus is strongly affected by the number of connections/network space the gene maintains. However, the direct relationship that duplication processes have on modularity has yet to be directly examined.

[3] Stabilizing Selection: While seeming antithetical to forming novel modules, Wagner maintains that it is important to consider the effects of stabilizing selection as it may be "an important counter force against the evolution of modularity". Stabilizing selection, if ubiquitously spread across the network, could then be a "wall" that makes the formation of novel interactions more difficult and maintains previously established interactions. Against such strong positive selection, other evolutionary forces acting on the network must exist, with gaps of relaxed selection, to allow focused reorganization to occur.

[4] Compounded effect of stabilizing and directional selection: This is the explanation seemingly favored by Wagner and his contemporaries as it provides a model through which modularity is constricted, but still able to unidirectionally explore different evolutionary outcomes. The semi-antagonistic relationship is best illustrated using the corridor model, whereby stabilizing selection forms barriers in *phenotype space* that only allow the system to move towards the *optimum* along a single path. This allows directional selection to act and inch the system closer to optimum through this evolutionary corridor.

For over a decade, researchers examined the dynamics of selection on network modularity. However, a 2013 publication calls into the question focusing solely on selective forces and instead provides evidence that there are inherent "connectivity costs" that limit the number of connections between nodes to maximize efficiency of transmission. This hypothesis originated from neurological studies that found that there is an inverse relationship between the number of neural connections and the overall efficiency (more connections seemed to limit the overall performance speed/precision of the network). This connectivity cost had yet to be applied to evolutionary analyses. Clune et al. created a series of models that compared the efficiency of various *evolved* network topologies in an environment where performance, their only metric for selection, was taken into account, and another treatment where performance as well as the connectivity cost were factored together. The results show not only that modularity formed ubiquitously in the models that factored in connection cost, but that these models also outperformed the performance-only based counterparts in every task. This suggests a potential model for module evolution whereby modules form from a system's tendency to resist maximizing connections to create more efficient and compartmentalized network topologies.

15.5 Development constraints on Evolution

15.5 Developmental constraints on evolution

A lineage's development may limit the sorts of phenotypes that it can evolve. This limitation is called a developmental constraint.

The idea of constrain help us why some things *didn't* happen in evolution that we might think would be advantageous: why *didn't* any tetrapods evolve more than five real fingers and toes, why *didn't* caterpillars evolve to have the complex eye of adult butterflies, and why *didn't* pigs evolve wings? Although difficult to figure out, the answers to these questions likely have to do with the developmental processes of tetrapods, insects, and pigs. Perhaps these features would fatally interrupt other aspects of the organism's development — or perhaps these features would require so many other drastic changes in development that they are unlikely to arise through mutation.

To look at an example in more detail, horses (and all tetrapods — from sloths to salamanders) develop through a stage where the embryo has limbs with five digits, even though some of these will be lost or greatly modified. One might think that it would be advantageous for horses to develop hooves directly, but they don't — they retain the five-digit developmental stage. The explanation for this may be developmental in nature — skipping the five-digit stage may simply not be an option in tetrapods' developmental processes.

Another consequence of interacting modules is that these interactions limit the possible phenotypes that can be created, and they also allow change to occur in certain directions more easily than in others. Collectively, these restraints on phenotype production are called **developmental constraints**

15.5.1 Physical constrains

There are only about three dozen animal phyla, constituting the major body plans of the animal kingdom. One can easily imagine other types of body plans and animals that do not exist. (Science fiction writers do it all the time.) Why aren't there more major body types among the animals? To answer this, we have to consider the constraints that development imposes on evolution. There are three major classes of constraints on morphogenetic evolution.

First, there are physical constraints on the construction of the organism. The laws of diffusion, hydraulics, and physical support allow only certain mechanisms of development to occur. One cannot have a vertebrate on wheeled appendages (of the sort that Dorothy saw in Oz) because blood cannot circulate to a rotating organ; this entire possibility of evolution has been closed off. Similarly, structural parameters and fluid dynamics forbid the existence of 5-foot-tall mosquitoes.

The elasticity and tensile strengths of tissues is also a physical constraint. The six cell behaviors used in morphogenisis (cell division, growth, shape change, migration, death, and matrix secretion) are each limited by physical parameters, and thereby provide limits on what structures animals can form. Interactions between different sets of tissues involves coordinating the behaviors of cell sheets, rods, and tubes in a limited number of way.

15.5.2Morphogenetic constrains

There are also constraints involving morphogenetic construction rules (Oster et al. 1988). Bateson (1894) and Alberch (1989) noted that when organisms depart from their normal development, they do so in only a limited number of ways. Some of the best examples of these types of constraints come from the analysis of limb formation in vertebrates. Holder (1983) pointed out that although there have been many modifications of the vertebrate limb over 300 million years, some modifications (such as a middle digit shorter than its surrounding digits) are not found. Moreover, analyses of natural populations suggest that there is a relatively small number of ways in which limb changes can occur (Wake and Larson 1987). If a longer limb is favorable in a given environment, the humerus may become elongated, but one never sees two smaller humeri joined together in tandem, although one could imagine the selective advantages that such an arrangement might have. This observation indicates a construction scheme that has certain rules.

The rules governing the architecture of the limb may be the rules of the reaction-diffusion model . Oster and colleagues (1988) found that the reaction-diffusion model can explain the known morphologies of the limb and can explain why other morphologies are forbidden. The reaction-diffusion equations predict the observed succession of bones from stylopod (humerus/femur) to zeugopod (ulna-radius/tibia-fibula) to autopod (hand/foot). If limb morphology is indeed determined by the reaction-diffusion mechanism, then spatial features that cannot be generated by reaction-diffusion kinetics will not occur.

Evidence for this mathematical model comes from experimental manipulations, comparative anatomy and cell biology. When an axolotl limb bud is treated with the anti-mitotic drug colchicine, the dimensions of the limb are reduced. In these experimental limbs, there is not only a reduction in the number of digits, but a loss of certain digits in a certain order, as predicted by the mathematical model and from the "forbidden" morphologies. Moreover, these losses of specific digits produce limbs very similar to those of certain salamanders whose limbs develop from particularly small limb buds. The self-organization of chondrocytes into nodules can be modelled by the Turing equations, and TGF-β2 appears to have the properties of the activator molecule postulated by this hypothesis. Thus, the use of reaction-diffusion mechanisms to construct limbs may constrain the possibilities that can be generated during development, because only certain types of limbs are possible under these rules.

15.5.3 Phyletic constrain

Phyletic constraints constitute the third set of constraints on the evolution of new types of structures (Gould and Lewontin 1979). These are historical restrictions based on the genetics of an organism's development. For instance, once a structure comes to be generated by inductive interactions, it is difficult to start over again. The notochord, for example, which is still functional in adult protochordates such as amphioxus (Berrill 1987), is considered vestigial in adult vertebrates. Yet it is transiently necessary in vertebrate embryos, where it specifies the neural tube. Similarly,Waddington (1938) noted that although the pronephric kidney of the chick embryo is considered vestigial (since it has no ability to concentrate urine), it is the source of the ureteric bud that induces the formation of a functional kidney during chick development.

Until recently, it was thought that the earliest stages of development would be the hardest to change, because altering them would either destroy the embryo or generate a radically new phenotype. But recent work has shown that alterations can be made to early cleavage without upsetting the final form. Evolutionary modifications of cytoplasmic determinants in mollusc embryos can give rise to new types of larvae that still metamorphose into molluscs, and changes in sea urchin cytoplasmic determinants can generate sea urchins that develop without larvae but still become sea urchins. In fact, while all the vertebrates arrive at a particular stage of development called the pharyngula, they do so by very different means . Birds, reptiles, and fishes arrive there after meroblastic cleavages of different sorts; amphibians get to the pharyngula stage by way of radial holoblastic cleavage; and mammals reach the same stage after constructing a blastocyst, chorion, and amnion. The earliest stages of development, then, appear to be extremely plastic. Similarly, the later stages are very different, as the different phenotypes of mice, sunfish, snakes, and newts amply demonstrate. There is something in the middle of development, however, that appears to be invariant.

Raff (1994) argues that the formation of new body plans (*Baupläne*) is inhibited by the need for global sequences of induction during the neurula stage. Before that stage, there are few inductive events. After that stage, there are a great many inductive events, but almost all of them occur within discrete modules. During early organogenesis, however, there are several inductive events occurring simultaneously that are global in nature. At this stage, the modules overlap and interact with one another. In vertebrates, to use von Baer's example, the earliest stages of development involve specifying axes and undergoing gastrulation. Induction has not yet happened on a large scale. Moreover, as Raff and colleagues have shown (Henry et al. 1989), there is a great deal of regulative ability at these stages, so small changes in morphogen distributions or the position of cleavage planes can be accommodated. After the major body plan is fixed, inductions occur all over the body, but are compartmentalized into discrete organ-forming systems. The lens induces the cornea, but if it fails to do so, only the eye is affected. Similarly, there are inductions in the skin that form feathers, scales, or fur. If they do not occur, the skin or patch of skin may lack these structures, but the rest of the body is unchanged. But during early organogenesis, the interactions are more global (Slack 1983). Failure to have the heart in a certain place can affect the induction of eyes . Failure to induce the mesoderm in a certain region leads to malformations of the kidneys, limbs, and tail. It is this stage that constrains evolution and that typifies the vertebrate phylum. Thus, once a vertebrate, it is difficult to evolve into anything else.

15.6 Creating Cell lines

Generating new stem cell lines is a major focus of many CIRM-funded researchers. Learn why these new lines are considered so important as we accelerate discoveries from the lab bench to the patient's bedside.

15.6.1 Stem cell line:

A stem cell line is a group of identical stem cells that can be grown and nurtured in a lab dish. A line originates with either a single induced pluripotent stem cell or from the cells of a five-day-old blastocyst—*and all resulting cells in the line are replicates of the original cells*. Researchers working with these lines can grow large volumes of cells. They can even freeze some in liquid nitrogen for future use or to share with colleagues.

We are still learning the best way to grow and maintain stem cells. The cells need nutrients and a recipe of biological factors in the lab dish in order to grow well. Figuring out the best combination of factors to maintain a stem cell line is the focus of several CIRM grants.

15.6.2 Different ways of creating pluripotent stem cell lines:

There are many different approaches to creating new cell lines. CIRM considers this to be such an important endeavor that it has funded $23 million in grants dedicated to the creation of new cell lines and to techniques that make the process more efficient:

15.6.2.1Option 1: In vitro fertilization

All human embryonic stem cell lines in use today were created from embryos generated by vitro fertilization (IVF) and *donated by the couple for research purposes*. In IVF, researchers mix a man's sperm and a woman's eggs together in a lab dish. Some of those eggs will become fertilized. After fertilization, the cells divide for about five days to form a ball of cells called a *blastocyst*.

The blastocyst is essentially a hollow ball of cells containing an inner clump that is known as the inner cell mass. This clump is what give rise to embryonic stem cells if grown in a dish. To generate an embryonic stem cell line, a researcher removes the outer layer of the five-day-old blastocyst then puts the remaining portion on a lab dish containing factors that allow cells of the inner cell mass to grow and thrive. These cells form the basis of a new embryonic stem cell line.

15.6.2.2 Option 2: Nuclear Transfer

Another method called stem cell nuclear transfer (SCNT) involves removing the genetic material from an egg, then injecting a different set of genetic material from an adult person's cell into that egg. Researchers then stimulate the egg to begin maturing. About five days later the egg develops into a *blastocyst*—the same type of blastocyst that would be used to create cell lines from donated IVF embryos. Researchers remove the inner cell mass from the blastocyst and grow those cells in a lab dish to create a new stem cell line.

Researchers have used SCNT to create stem cell lines from a wide range of animals including non-human primates. In 2013, scientists for the first time created human stem cell lines through nuclear transfer.

Embryonic stem cells created through SCNT have the advantage of being genetically identical to a person's *own* cells, reducing the risk of immune rejection.

The process of using nuclear transfer to create cell lines identical to a person's own cells is sometimes referred to as *therapeutic cloning*. That's because those identical stem cells would be created with the intent to derive therapies.

Therapeutic cloning should not be confused with reproductive cloning, in which the intent is to create an identical human being. The California constitution, CIRM regulations and all other states that are actively supporting stem cell research expressly prohibit human reproductive cloning.

15.6.2.3 Option 3: Induced Pluripotent Stem Cells

The first human induced pluripotent stem (iPS) cells were created by inserting four genes into the DNA of human skin cells. Those introduced genes effectively turned back the clock, causing the adult skin cells to revert back to an embryonic-like state, rendering them pluripotent.

These cells are an exciting and valuable research tool, however, iPS cells face some hurdles before they can advance towards clinical trials. For example, the earliest versions of the technique used a virus to shuttle the genes into the skin cell, which can integrate into the cell's DNA and possibly cause hazardous mutations. What's more, some of the genes used to create the iPS cells have some cancer-causing potential.

Many CIRM-funded researchers are working to identify safer ways of creating iPS cells, which would allow researchers to create patient-specific stem cells that can be transplanted as a treatment for disease. These researchers are looking into using methods that don't require the genes to incorporate into the cell's DNA or finding a combination of chemicals or proteins to replace those genes as alternative ways of creating iPS cells.

15.7 Summary

The environment regulates the development of an animal which is evident in the larval settlement of some marine invertebrates governed by the re algal settlement in the surroundings. In many mosquitoes egg production is triggered by a blood meal. In some individuals the development is made possible by the presence of another individual of a different species. In fact some aphids have their sexuality determined by the specific season. There are some complex environment on development as well like diapauses , polyphenism and reaction norms .The temperature also plays an important role in the sex determination in some species.The predator too induces polyphenism in some cases. Modularity refers to the ability of a system to organize discrete individual units that can overall increase the efficiency of network activity. There are four potential evolutionary modes of action responsible for maintaining modularity namely selection for the rate of adaption, construction selection, stabilizing selection and compounded effect of stabilizing and directional selection. Development constraints on evolution includes physical , morphogenetic and phyletic constraints. Creating of new cell line can be done by in-vitro fertilization, nuclear transfer and induced pluripotent stem cells.

15.8 Glossary

- **Diapause:** It is a suspension of development that can occur at the embryonic ,larval, pupal or adult stage, depending on the species.
- Polyphenism: It refers to discontinuous phenotypes elicited by the environment.
- **Reaction Norms:**The continuous range of phenotypes expressed by a single genotype across a range of environmental conditions is called the reaction norms
- **Kairomones:** Chemicals that are released by a predator and can induce defenses in the prey are called kairomones.
- **Modularity:** It refers to the ability of a system to organize discrete individual units that can overall increase the efficiency of network

activity and in biological sense facilitates selective forces upon the network.

- **Phyletic constrain:** These are historical restrictions bases on the genetics of an organisms development
- **Stem Cell Line:** A stem cell line is a group of identical stem cells that can be grown and nurtured in a lab dish.

15.9 Self Learning Exercises

Section (A):Very Short Answer type Questions

1. What are induced Pluripotent stem cells?
2. Expand SCNT.
3. Name a molluscan larva which requires red algae for its settlement.
4. Which blood sucking bug reproduces a new batch of eggs after a blood meal?
5. Name a suid involved in developmental symbiosis.

Section (B):Short Answer type Questions

1. Explain Phenotypic Plasticity.
2. Differentiate between Nutritional and Polyphenism for alternative conditions
3. Write a short note on Developmental Constraints.
4. Write a note on environment dependent sex determination.

Section(C):Long Answer Type Questions

1. Explain how environment can effect the development of an individual citing examples from the test studied by you.
2. Write an essay on Modularity.

Unit -16

Sex Determination

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Structure of the Unit

16.0 Objectives

After going through this unit you will be able to understand

- What is sex determination?
- How primitive gonad can convert into both male and female?
- Mechanism of primary and secondary sex determinations?
- How environment influences the type of sex ?

16.1 Introduction

A sex-determination system is a biological system that determines the development of sexual characteristics in anorganism. Most organisms that create their offspring using sexual reproduction have two sexes. Occasionally, there arehermaphrodites in place of one or both sexes. There are also some species that are only one sex due to parthenogenesis, the act of a female reproducing without fertilization.

In many species, sex determination is genetic: males and females have different alleles or even different genes that specify their sexual morphology. In animals this is often accompanied by chromosomal differences, generally through combinations of XY, ZW, XO, ZO chromosomes, or haplodiploidy. The sexual differentiation is generally triggered by a main gene (a "sex locus"), with a multitude of other genes following in a domino effect.

In other cases, sex is determined by environmental variables (such as temperature) or social variables (e.g. the size of an organism relative to other members of its population). Environmental sex determination preceded the genetically determined systems of birds and mammals; it is thought that a temperature-dependent amniote was the common ancestor of amniotes with sex chromosomes.

Some species do not have a fixed sex, and instead change sex based on certain cues. The details of some sex-determination systems are not yet fully understood.

16.2 Primary and secondary sex determination

16.2.1. Primary sex determination is the determination of the gonads. In mammals, primary sex determination is strictly chromosomal and is not usually influenced by the environment. In most cases, the female is XX and the male is XY. Every individual must have at least one X chromosome. Since the female is XX, each of her eggs has a single X chromosome. The male, being XY, can generate two types of sperm: half bear the X chromosome, half the Y. If the egg receives another X chromosome from the sperm, the resulting individual is XX, forms ovaries, and is female; if the egg receives a Y chromosome from the sperm, the individual is XY, forms testes, and is male. The Y chromosome carries a gene that encodes a testis-determining factor. This factor organizes the gonad into a testis rather than an ovary. Unlike the situation in *Drosophila* (discussed below), the mammalian Y chromosome is a crucial factor for determining sex in mammals. A person with five X chromosomes and one Y chromosome (XXXXXY) would be male. Furthermore, an individual with only a single X chromosome and no second X or Y (i.e., XO) develops as a female and begins making ovaries, although the ovarian follicles cannot be maintained. For a complete ovary, a second X chromosome is needed.

In mammalian primary sex determination, there is no "default state." The formation of ovaries and testes are both active, gene-directed processes. Moreover, as we shall see, both diverge from a common precursor, the bipotential gonad.

16.2.2 Secondary sex determination affects the bodily phenotype outside the gonads. A male mammal has a penis, seminal vesicles, and prostate gland. A female mammal has a vagina, cervix, uterus, oviducts, and mammary glands. In many species, each sex has a sex-specific size, vocal cartilage, and musculature. These secondary sex characteristics are usually determined by hormones secreted from the gonads. However, in the absence of gonads, the female phenotype is generated. When Jost (1953) removed fetal rabbit gonads before they had differentiated, the resulting rabbits had a female phenotype, regardless of whether they were XX or XY. They each had oviducts, a uterus, and a vagina, and each lacked a penis and male accessory structures.

If the Y chromosome is absent, the gonadal primordia develop into ovaries. The ovaries produce estrogen, a hormone that enables the development of theMüllerian duct into the uterus, oviducts, and upper end of the vagina. If the Y chromosome is present, testes form and secrete two major hormones. The first hormone—anti-Müllerian duct hormone (AMH; also referred to as Müllerian-inhibiting substance, MIS)—destroys the Müllerian duct. The second hormone—testosterone—masculinizes the fetus, stimulating the formation of the penis, scrotum, and other portions of the male anatomy, as well as inhibiting the development of the breast primordia. Thus, the body has the female phenotype unless it is changed by the two hormones secreted by the fetal testes. We will now take a more detailed look at these events.

16.3 Developing gonads

The gonads embody a unique embryological situation. All other organ rudiments can normally differentiate into only one type of organ. A lung rudiment can become only a lung, and a liver rudiment can develop only into a liver. The gonadal rudiment, however, has two normal options. When it differentiates, it can develop into either an ovary or a testis. The path of differentiation taken by this rudiment determines the future sexual development of the organism. But, before this decision is made, the mammalian gonad first develops through a bipotential (indifferent) stage, during which time it has neither female nor male characteristics.

In humans, the gonadal rudiments appear in the intermediate mesoderm during week 4 and remains sexually indifferent until week 7. The gonadal rudiments are paired regions of the intermediate mesoderm; they form adjacent to the developing kidneys. The ventral portions of the gonadal rudiments are composed of the genital ridge epithelium. During the indifferent stage, the genital ridge epithelium proliferates into the loose connective mesenchymal tissue above. These epithelial layers form the sex cords. The germ cells migrate into the gonad during week 6, and are surrounded by the sex cords. In both XY and XX gonads, the sex cords remain connected to the surface epithelium.

If the fetus is XY, the sex cords continue to proliferate through the eighth week, extending deeply into the connective tissue. These cords fuse, forming a network of internal (medullary) sex cords and, at its most distal end, the thinner rete testis. Eventually, the sex cords—now called testis cords—lose contact with the surface epithelium and become separated from it by a thick extracellular matrix, the tunica albuginea. Thus, the germ cells are found in the cords within the testes. During fetal life and childhood, the testis cords remain solid. At puberty, however, the cords will hollow out to form the seminiferous tubules, and the germ cells will begin to differentiate into sperm.

The cells of the seminiferous tubule are called Sertoli cells. The Sertoli cells of the testis cords nurture the sperm and secrete anti-Müllerian duct hormone. The sperm are transported from the inside of the testis through the rete testis, which joins the efferent ducts. These efferent tubules are the remnants of the mesonephric kidney, and they link the testis to the Wolffian duct, which used to be the collecting tube of the mesonephric kidney. In males, the Wolffian duct differentiates to become the epididymis (adjacent to the testis) and the vas deferens, the tube through which the sperm pass into the urethra and out of the body. Meanwhile, during fetal development, the interstitial mesenchyme cells of the testes differentiate into Leydig cells, which make testosterone.

In females, the germ cells will reside near the outer surface of the gonad. Unlike the sex cords in males, which continue their proliferation, the initial sex cords of XX gonads degenerate. However, the epithelium soon produces a new set of sex cords, which do not penetrate deeply into the mesenchyme, but stay near the outer surface (cortex) of the organ. Thus, they are called cortical sex cords. These cords are split into clusters, with each cluster surrounding a germ cell. The germ cells will become the ova, and the surrounding cortical sex cords will differentiate into thegranulosa cells. The mesenchyme cells of the ovary differentiate into the thecal cells. Together, the thecal and granulosa cells will form the follicles that envelop the germ cells and secrete steroid hormones. Each follicle will contain a single germ cell. In females, the Müllerian duct remains intact, and it differentiates into the oviducts, uterus, cervix, and upper vagina. The Wolffianduct, deprived of testosterone, degenerates.

16.4 Mechanism of primary sex determination

Several genes have been found whose function is necessary for normal sexual differentiation. Unlike those that act in other developing organs, the genes involved in sex determination differ extensively between phyla, so one cannot look at *Drosophila* sex-determining genes and expect to see their homologues directing mammalian sex determination.

16.4.1 Sry: the Y chromosome sex determinant

In humans, the major gene for the testis-determining factor resides on the short arm of the Y chromosome. Individuals who are born with the short arm but not the long arm of the Y chromosome are male, while individuals born with the long arm of the Y chromosome but not the short arm are female. By analyzing the DNA of rare XX men and XY women, the position of the testis-determining gene has been narrowed down to a 35,000-base-pair region of the Y chromosome located near the tip of the short arm. In this region, Sinclair and colleagues (1990) found a male-specific DNA sequence that could encode a peptide of 223 amino acids. This peptide is probably a transcription factor, since it contains a DNA-binding domain called the HMG (*h*igh-*m*obility *g*roup) box. This domain is found in several transcription factors and nonhistone chromatin proteins, and it induces bending in the region of DNA to which it binds. This gene is called *SRY* (*s*ex-determining *r*egion of the *Y* chromosome), and there is extensive evidence that it is indeed the gene that encodes the human testis-determining factor. *SRY* is found in normal XY males and in the rare XX males, and it is absent from normal XX females and from many XY females. Another group of XY females was found to have point or frameshift mutations in the *SRY* gene; these mutations prevent the SRY protein from binding to or bending DNA (Pontiggia et al. 1994; Werner et al. 1995). It is thought that several testis-specific genes contain SRY-binding sites in their promoters or enhancers, and that the binding of SRY to these sites begins the developmental pathway to testis formation (Cohen et al. 1994).

If *SRY* actually does encode the major testis-determining factor, one would expect that it would act in the genital ridge immediately before or during testis differentiation. This prediction has been met in studies of the homologous gene found in mice. The mouse gene (*Sry*) also correlates with the presence of testes; it is present in XX males and absent in XY females (Gubbay et al. 1990; Koopman et al. 1990). The *Sry* gene is expressed in the somatic cells of the bipotential mouse gonad immediately before or during its differentiating into a testis; its expression then disappears (Hacker et al. 1995).

Sry/SRY is necessary, but not sufficient, for the development of the mammalian testis. Studies on mice (Eicher and Washburn 1983; Washburn and Eicher 1989; Eicher et al. 1996) have shown that the *Sry* gene of some strains of mice failed to produce testes when placed into a different strain of mouse. When the Sry protein binds to its sites on DNA, it probably creates large conformational changes. It unwinds the double helix in its vicinity and bends the DNA as much as 80 degrees (Pontiggia et al. 1994; Werner et al. 1995). This bending may bring distantly bound proteins of the transcription apparatus into close contact, enabling them to interact and influence transcription. The identities of these proteins are not yet known, but they, too, are needed for testis determination.

16.4.2 Sox9: autosomal sex reversal

One of the autosomal genes involved in sex determination is *SOX9*, which encodes a putative transcription factor that also contains an HMG box. XX humans who have an extra copy of *SOX9* develop as males, even though they have no*SRY* gene. Individuals having only one functional copy of this gene have a syndrome called campomelic dysplasia, a disease involving numerous skeletal and organ systems. About 75% of XY patients with this syndrome develop as phenotypic females or hermaphrodite. It appears that *SOX9* is essential for testis formation. The mouse homologue of this gene, *Sox9,* is expressed only in male (XY) but not in female (XX) genital ridges. Moreover, *Sox9* expression is seen in the same genital ridge cells as*Sry,* and it is expressed just slightly after *Sry* expression. The Sox9 protein binds to a promoter site on the *Amh* gene, providing a critical link in the pathway toward a male phenotype .

16.4.3 Sf1: the link between sry and the male developmental pathways

Another protein that may be directly or indirectly activated by SRY is the transcription factor SF1 (*s*teroidogenic *f*actor*1*). *Sf1* is necessary to make the bipotential gonad; but while Sf1 levels decline in the genital ridge of XX mouse embryos, the *Sf1* gene stays on in the developing testis. Sf1 appears to be active in masculinizing both the Leydig and the Sertoli cells. In the Sertoli cells, Sf1, working in collaboration with Sox9, is needed to elevate the levels of AMH transcription. In the Leydig cells, Sf1 activates the genes encoding the enzymes that make testosterone. The importance of SF1 for testis development and AMH regulation in humans is demonstrated by an XY patient who is heterozygous for *SF1*.

16.4.4 Dax1: a potential ovary-determining gene on the X chromosome

In 1980, Bernstein and her colleagues reported two sisters who were genetically XY. Their Y chromosomes were normal, but they had a duplication of a small portion of the short arm of the X chromosome. Subsequent cases were found, and it was concluded that if there were two copies of this region on the active X chromosome, the SRY signal would be reversed (Figure 17.9). Bardoni and her colleagues (1994) proposed that this region contains a gene for a protein that competes with the SRY factor and that is important in directing the development of the ovary. In testicular development, this gene would be suppressed, but having two active copies of the gene would override this suppression. This gene, *DAX1*, has been cloned and shown to encode a member of the nuclear hormone receptor family. *Dax1* is expressed in the genital ridges of the mouse embryo, shortly after *Sry* expression. Indeed, in XY mice, *Sry* and *Dax1* are expressed in the same cells. DAX1 appears to antagonize the function of SRY, and it down-regulates SF1 expression (Nachtigal et al. 1998; Swain et al. 1998). Thus, *DAX1* is probably a gene that is involved in ovary determination.

16.4.5 Wnt4: a potential ovary-determining gene on an autosome

The *WNT4* gene is another gene that may be critical in ovary determination. This gene is expressed in the mouse genital ridge while it is still in its bipotential stage. *Wnt4* expression then becomes undetectable in XY gonads (which become testes), whereas it is maintained in XX gonads as they begin to form ovaries. In transgenic XX mice that lack the *Wnt4*genes, the ovary fails to form properly, and its cells express testis-specific markers, including AMH-and testosterone-producing enzymes. Sry may form testes by repressing *Wnt4* expression in the genital ridge, as well as by promoting *Sf1*.

16.5 Mechanism of secondary sex detrmination

Primary sex determination involves the formation of either an ovary or a testis from the bipotential gonad. This, however, does not give the complete sexual phenotype. Secondary sex determination in mammals involves the development of the female and male phenotypes in response to hormones secreted by the ovaries and testes. Both female and male secondary sex determination have two major temporal phases. The first occurs within the embryo during organogenesis; the second occurs during adolescence.

As mentioned earlier, if the bipotential gonads are removed from an embryonic mammal, the female phenotype is realized: the Müllerian ducts develop while the Wolffian duct degenerates. This pattern also is seen in certain humans who are born without functional gonads. Individuals whose cells have only one X chromosome (and no Y chromosome) originally develop ovaries, but these ovaries atrophy before birth, and the germ cells die before puberty. However, under the influence of estrogen, derived first from the ovary but then from the mother and placenta, these infants are born with a female genital tract.

The formation of the male phenotype involves the secretion of two testicular hormones. The first of these hormones is AMH, the hormone made by the Sertoli cells that causes the degeneration of the Müllerian duct. The second is the steroid testosterone, which is secreted from the fetal Leydig cells. This hormone causes the Wolffian duct to differentiate into the epididymis, vas deferens, and seminal vesicles, and it causes the urogenital swellings to develop into the scrotum and penis.

The existence of these two independent systems of masculinization is demonstrated by people having androgen insensitivity syndrome. These XY individuals have the *SRY* gene, and thus have testes that make testosterone and AMH. However, they lack the testosterone receptor protein, and therefore cannot *respond* to the testosterone made by their testes. Because they are able to respond to estrogen made in their adrenal glands, they develop the female phenotype. However, despite their distinctly female appearance, these individuals do have testes, and even though they cannot respond to testosterone, they produce and respond to AMH. Thus, their Müllerian ducts degenerate. These people develop as normal but sterile women, lacking a uterus and oviducts and having testes in the abdomen.

Testosterone and dihydrotestosterone

Although testosterone is one of the two primary masculinizing hormones, there is evidence that it might not be the active masculinizing hormone in certain tissues. Testosterone appears to be responsible for promoting the formation of the male reproductive structures (the epididymis, seminal vesicles, and vas deferens) that develop from the Wolffian duct primordium. However, it does not directly masculinize the male urethra, prostate, penis, or scrotum. These latter functions are controlled by 5a-dihydrotestosterone . Siiteri and Wilson (1974) showed that testosterone is converted to 5α-dihydrotestosterone in the urogenital sinus and swellings, but not in the Wolffian duct. 5α-dihydrotestosterone appears to be a more potent hormone than testosterone.

The importance of 5α-dihydrotestosterone was demonstrated by Imperato-McGinley and her colleagues (1974). They found a small community in the Dominican Republic in which several inhabitants had a genetic deficiency of the enzyme 5α-ketosteroidreductase 2, the enzyme that converts testosterone to dihydrotestosterone. These individuals lack a functional gene for this enzym. Although XY children with this syndrome have functioning testes, they have a blind vaginal pouch and an enlarged clitoris. They appear to be girls and are raised as such. Their internal anatomy, however, is male: they have testes, Wolffian duct development, and Müllerian duct degeneration. Thus, it appears that the formation of the external genitalia is under the control of dihydrotestosterone, whereas Wolffian duct differentiation is controlled by testosterone itself. Interestingly, when the testes of these children produce more testosterone at puberty, the external genitalia are able to respond to the higher levels of the hormone, and they differentiate. The penis enlarges, the scrotum descends, and the person originally thought to be a girl is shown to be a young man.

16.6 Environmental sex determination

16.6.1 Temperature-dependent sex determination

Many other sex-determination systems exist. In some species of reptiles, including alligators, some turtles, and the tuatara, sex is determined by the temperature at which the egg is incubated during a temperature-sensitive period. There are no examples of temperature-dependent sex determination (TSD) in birds. Megapodes had formerly been thought to exhibit this phenomenon, but actually exhibit temperature-dependent embryo mortality.

For some species with TSD, sex determination is achieved by exposure to hotter temperatures resulting in the offspring being one sex and cooler temperatures resulting in the other. For others species using TSD, it is exposure to temperatures on both extremes that results in offspring of one sex, and exposure to moderate temperatures that results in offspring of the opposite sex. These systems are known as Pattern I and Pattern II, respectively. The specific temperatures required to produce each sex are known as the female-promoting temperature and the male-promoting temperature.When the temperature stays near the threshold during the temperature sensitive period, the sex ratio is varied between the two sexes. Some species' temperature standards are based on when a particular enzyme is created. These species that rely upon temperature for their sex determination do not have the SRY gene, but have other genes such as DAX1, DMRT1, and SOX9 that are expressed or not expressed depending on the temperature. The sex of some species, such as the Nile tilapia, Australian skink lizard, and Australian dragon lizard, is initially determined by chromosomes, but can later be changed by the temperature of incubation.

It is unknown how exactly temperature-dependent sex determination evolved. It could have evolved through certain sexes being more suited to certain areas that fit the temperature requirements. For example, a warmer area could be more suitable for nesting, so more females are produced to increase the amount that nest next season.

16.6.2 Other sex-determination systems

Although temperature-dependent sex determination is relatively common, there are many other environmental systems. Some species, such as some snails, practice sex change: adults start out male, then become female. In tropical clown fish, the dominant individual in a group becomes female while the other ones are male, and bluehead wrasses (*Thalassomabifasciatum*) are the reverse. In the marine worm (*Bonelliaviridis*), larvae become males if they make physical contact with a female, and females if they end up on the bare sea floor. This is triggered by the presence of a chemical produced by the females,bonellin. Some species, however, have no sex-determination system. Hermaphrodite species include the common earthworm and certain species of snails. A few species of fish, reptiles, and insects reproduce by parthenogenesis and are female altogether. There are some reptiles, such as the boa constrictor and Komodo dragon that can reproduce both sexually and asexually, depending on whether a mate is available.

1. XY set of chromosomes are termed as
1. allosomes
2. autosomes
3. anosomes
4. hetrosomes

2.A human male has ____ chromosomes with ____ sex chromosomes.

1. 46, XY 2. 48, XY
3. 46, XX 4. 48, XX

3. What is sex determination?

4. Describe the mechanism of primary sex determination?

5. Describe the mechanism of secondary sex determination?

Unit – 17

Programmed Cell Death, Ageing and Senescence

Structure of the Unit

17.0 Introduction

In most multicellular organisms' development and homeostasis are dependent on cell division, differentiation and cell death. During development, the balance between the process of cell division and cell death leads to the generation of proper number and type of cells in mature animal also. Around the year 1950, it was established that process of cell death is a normal activity of development and homeostasis. **So, the predetermined elimination of unwanted cells in a morphologically distinct manner (cells shrink and get phagocytosed) is described as programmed cell death (PCD). This phenomenon is contrary to** the pathological cell death caused due to cell injury (cell swell and burst to release toxins). Another term for cell death which is in common use is '**apoptosis'**, but all cell deaths are not apoptosis, as will be shown in this chapter. Apoptosis, as a programmed cell death (PCD) is essential for normal cell mechanism. It is a process that takes place within our cells as well as within the cells of many other organisms. It is a natural process that a cell can commit to and which eventually leads to the death of that cell. The word "Apoptosis" derives from Greek language "απόπτωσις" and means trees shedding their leaves in autumn, which describes the "dropping off" or "falling off" of petals from flowers, or as leaves from trees. This language imaginarily described the cell death triggered by physiological and pathological stimulation. The apoptosis phenomena were first described by German Scientist Carl Vogt in 1842 year, while until 1972 year, apoptosis term was first used by John Foxton Ross Kerr group.

In this chapter, we will mainly discuss the apoptosis and its mechanism. The following aspects of apoptosis, utilizing suitable examples, will also be discussed in this chapter: (i) the role which this process of apoptosis plays in differentiation and development, (ii) the specific genes which are involved in this process, (iii) the mechanism of its occurrence and the manner in which this process is regulated.

17.1. Features of Apoptosis

17.1.1.Two types of programmed cell death: apoptosis and autophagy:-

(i) Apoptosis, or type I programmed cell death:- It is the most widely studied forms of cell death and its morphological characteristics can be identified under light microscopy. Its morphological characteristics include mainly, cell shrinkage, condensation of chromatin, blebbing of the cytoplasmic membrane, and, finally, the formation of apoptotic bodies (Figure 1).

Apoptosis is characterized by the participation of proteases called caspases, orderly internucleosomal DNA fragmentation, phosphatidylserine externalization, changes in mitochondrial membrane permeability, and the participation of members of the Bcl-2 protein family.

(ii) Autophagic cell death, or type II programmed cell death:- It is characterized by a massive engulfing of the cytoplasm by autophagic vesicles. This intense autophagic activity differs substantially from autophagy that occurs continuously at basal levels.

It is a genetically programmed and evolutionarily conserved process that produces the degradation of obsolete organelles and proteins. It is activated by such extracellular stimuli as nutrient starvation, hypoxia, high temperature, and altered intracellular conditions, including the accumulation of damaged or superfluous organelles.

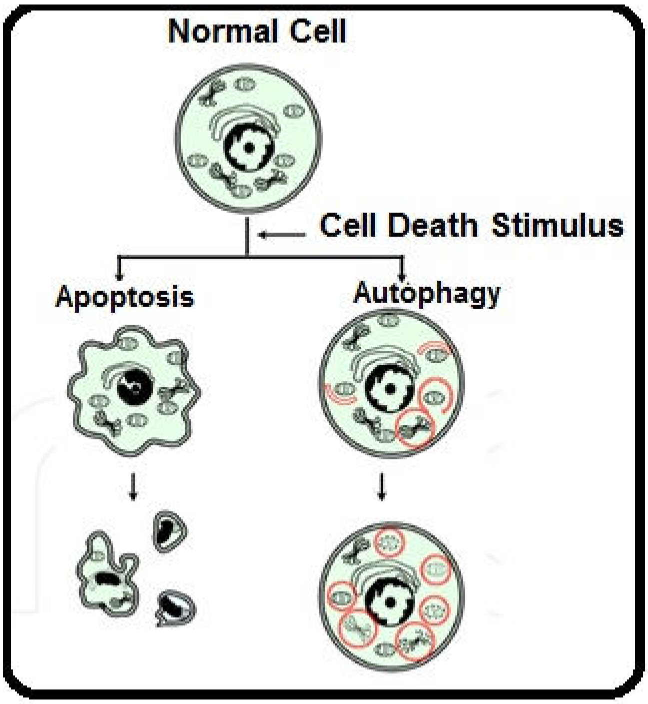

Figure 1. Schematic representation of the programmed cell death process type I (apoptosis) and type II (autophagy). (Source -Book Chapter "Necrosis as Programmed Cell Death http://dx.doi.org/10.5772/61483, Intech).

17.1.2.Non Apoptotic programmed cell death:-

In addition to these two major types of Programmed Cell Death, there are other pathways also have been discovered, called **"non- apoptotic programmed cell death".** This form of cell death is also called "caspase-independent programmed cell-death" or "necrosis-like programmed cell death". Cell death caused by necrosis is considered an accidental, unprogrammed event that occurs under total ATP depletion, and that results from such external stimuli as extreme physical– chemical stress, heat, osmotic shock, mechanical stress, freezing, thawing, and high concentrations of hydrogen peroxide.

Necrotic cell death is characterized morphologically by generalized swelling of cell membranes, often accompanied by chromatin condensation and an irregular DNA degradation pattern. The cytoplasmic membranes and membranous organelles dilate, and the increased cellular swelling causes the breakdown of the plasma membrane, which releases the cytoplasmic contents into the extracellular space (Figure 2). The release of the intracellular contents leads to massive cellular damage that affects nearby cells. This phenomenon explains why necrosis triggers inflammatory and autoimmune reactions. The necrosis process takes place in the absence of phagocytosis, and its final phase is characterized by the loss of the integrity of the cellular membrane. The release of the contents of necrotic cells includes molecules which act as signals that promote inflammation.

The most significant difference between programmed cell death (*i.e.*, apoptosis and autophagy) and necrosis is plasma membrane leakage and the consequent induction of inflammation in the affected tissue caused by the release of intracellular components.

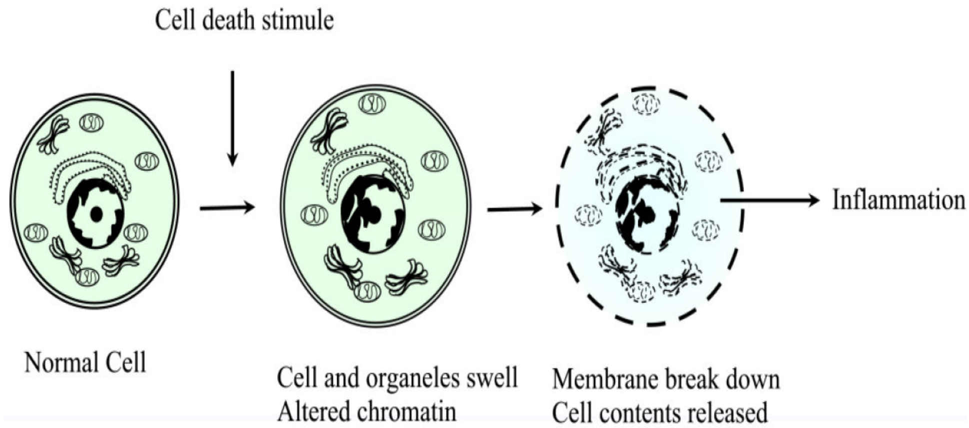

Figure 2. Necrosis involve the membranous swelling of the organelles, DNA degradation, and finally the release of the cytoplasmic content that affects the neighbor cells, provoking an inflammatory response (Source- Book Chapter "Necrosis as Programmed Cell Death http://dx.doi.org/10.5772/61483, Intech).

These alternative routes to death are as efficient an apoptosis and can function as either backup mechanisms or the main type of PCD. Other forms of PCD include (i) **anoikis**, almost identical to apoptosis expect in its induction; (ii) **cornification**, a form of cell death exclusive to the eyes; (iii) **excitotxibity** and (iv) **Wallerian degeneration**. Plant cells undergo particular processes of PCD, which are similar to autophagic cell death. However, some common features of PCD are highly conserved in both plant and metazoa.

17.2 Significance of Programmed Cell Death

The development and maintenance of multicellular biological systems depends on a sophisticated interplay between the cells forming the organism, it sometimes even seems to involve an altruistic behaviour of individual cells in favour of the organism as a whole. In development process, programmed cell death also exerts a role opposite to mitosis in the maintenance of cell populations and thereby contribute to sculpturing many organs and tissues. As many as 10^{11} cells die in an adult human per day to ensure tissue homeostasis. It is also estimated that within a typical year, the mass of cells a person loses through cell death is almost equivalent to their entire body weight. Such death therefore probably plays an important part in dynamic processes such as tissue remodelling and responses to stress. It is estimated that to maintain homeostasis in the adult human body, around 10 billion cells are made each day just to balance those dying by programmed cell death. And that number can increase significantly when there is increased apoptosis during normal development and aging or during disease.

Formation of free and independent digits by massive cell death in the interdigital mesenchymal tissues is a particularly instructive example for the implication of programmed cell death in animal development.

In the development of the nervous system, during which half or more of the nerve cells that are initially created will die in later stages. The development of the reproductive organs are other important examples. Also cells of an adult organism constantly undergo physiological cell death which must be balanced with proliferation in order to maintain homeostasis in terms of constant cell numbers. In a healthy adult human, billions of cells die in the bone marrow and intestine every hour. It seems remarkably wasteful for so many cells to die, especially as the vast majority are perfectly healthy at the time they kill themselves. The majority of the developing lymphocytes die either during genetic rearrangement events in the formation of the antigen receptor, during negative selection or in the periphery, thereby tightly controlling the pool of highly efficient and functional but not self-reactive immune cells and at the same time keeping lymphocyte numbers relatively constant.

Apoptotic processes are also necessary to get rid the body of pathogen-invaded cells and is a vital component of wound healing in that it is involved in the removal of inflammatory cells and the evolution of granulation tissue into scar tissue.

Taken together, apoptotic processes are of widespread biological significance, being involved in e.g. development, differentiation, proliferation/homoeostasis, regulation and function of the immune system and in the removal of defect and therefore harmful cells. Thus, dysfunction or dysregulation of the apoptotic program is implicated in a variety of pathological conditions. Excess cell death can contribute to the acquired immune deficiency syndrome (AIDS) and neurodegenerative disorders, like Alzheimer and Parkinson’s syndromes, and ischaemic injury such as myocardial infarction. Too little cell death could lead to cancer, persistent viral infection, or autoimmune disorders.

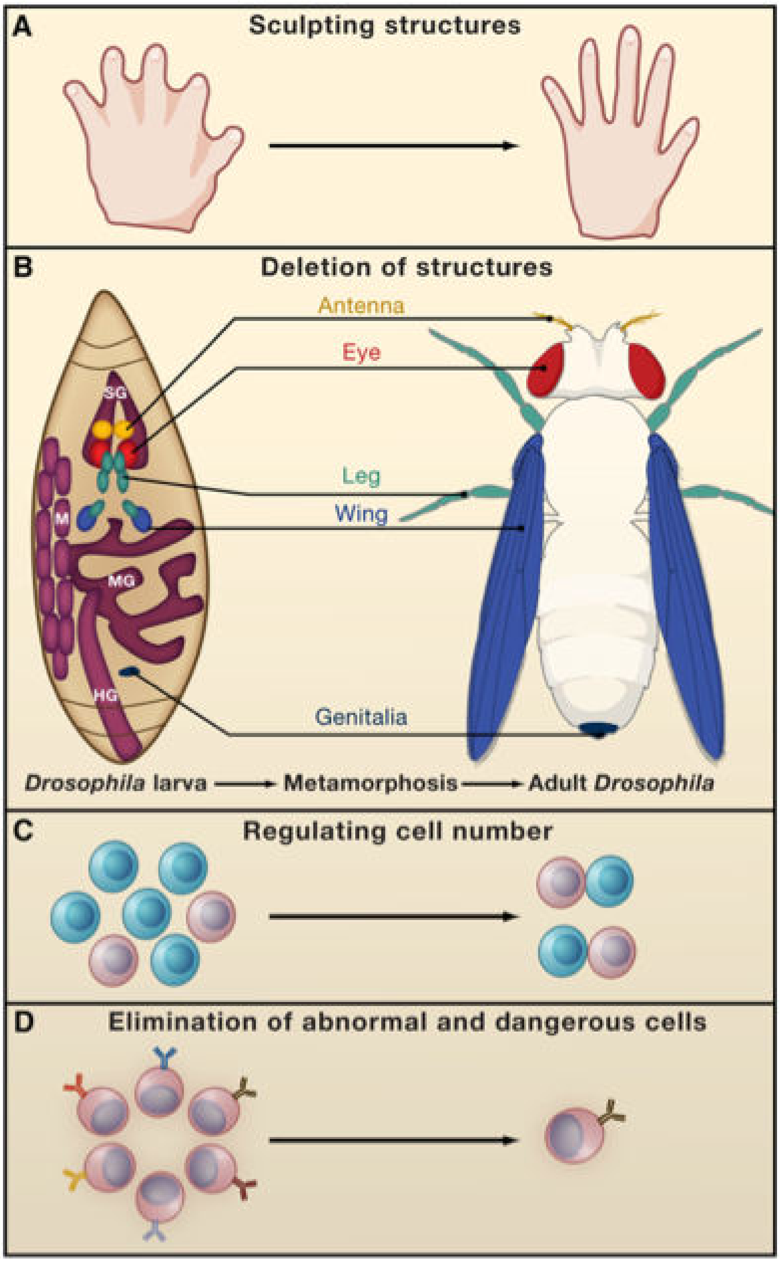

Figure 3. Shows role of programmed cell death in various processes.

17.3. Occurrence of Programmed Cell Death

Due to the importance of programmed cell death in such various biological processes, it is a widespread phenomenon, occurring in all kinds of metazoans such as in mammals, insects, nematodes, and cnidaria. Moreover, programmed cell death also might play a role in plant biology, and apoptosis-like cell death mechanisms even have been observed and used as a model system in yeast. Fascinating insights into the origin and evolution of programmed cell death might possibly be given by the fact, that programmed cell death is also an integral part of the life cycle of other unicellular eukaryotes (such as the kinetoplastid parasite Trypanosoma brucei brucei, the ciliate Tetrahymena thermophila, and the slime mold Dictyostelium discoideum) and that even prokaryotes (such as Bacillus subtilis, Streptomyces and Myxobacteria) sometimes undergo regulated cell death.

Although it's detailed analysis has been conducted only in some animal system. In the nematode, Coenorhabditis elegans cell death has been most extensively, exactly 131 cells die according to a well-regulated genetic program.

In vertebrates, cell death has been observed in all studied in the developing nervous system and immune system. Like Nematodes, in invertebrates also, cell death occurs in many tissues during development, including neurons, muscel cells, epithelial cells, intestinal cell and gonadal cells. Cell death or apoptosis has also been observed in microbial system/cell cultures and therefore is ubiquitous. Alterations in the programmed cell death leading to survival of those cells which were targeted to undergo cells death has also been found to cause a number of human diseases. For instance, if the cell destined for cell death survive in mutants, it may lead to cancer or autoimmune diseases, while excessive cell death may cause neurodegenerative disease and immunodeficiency (autoimmune disease means immunity against one's own cells or its constituents). In view of these, cell death or apoptosis has been an area of intensive research in recent years.

17.4. Morphological features of Programmed Cell Death

The morphological features of programmed cell death (PCD) or apoptosis is often associated with characteristic morphological and biochemical changes. Light and electron microscopy have identified the various morphological changes that occur during apoptosis. During the early process of apoptosis, cell shrinkage and chromatin condensation (Pyknosis) are visible by light microscopy. With cell shrinkage, the cells are smaller in size, the cytoplasm is dense and the organelles are more tightly packed. As Pyknosis is the result of chromatin condensation, this is the most characteristic feature of apoptosis. Histologic examination with hematoxylin and eosin stain shows that apoptosis involves single cells or small clusters of cells. The apoptotic cell appears as a round or oval mass with dark eosinophilic cytoplasm and dense purple nuclear chromatin fragments. Electron microscopy can better define the subcellular changes. Early during the chromatin condensation phase, the electron-dense nuclear material characteristically aggregates peripherally under the nuclear membrane although there can also be uniformly dense nuclei.

Extensive plasma membrane blebbing occurs followed by karyorrhexis and separation of cell fragments into apoptotic bodies during a process called "budding." Apoptotic bodies consist of cytoplasm with tightly packed organelles with or without a nuclear fragment (Figure 3). The organelle integrity is still maintained and all of this is enclosed within an intact plasma membrane. These bodies are subsequently engulf or phagocytosed by macrophages, parenchymal cells, or neoplastic cells and degraded within phagolysosomes. These bodies are removed without causing an inflammatory response because, these bodies do not release their cellular constituents into the surrounding interstitial tissue, they are quickly phagocytosed by surrounding cells thus likely preventing secondary necrosis; and, the engulfing cells do not produce antiinflammatory cytokines. Thus the dead cells are removed and any harm due to leakage of their dangerous contents are avoided.

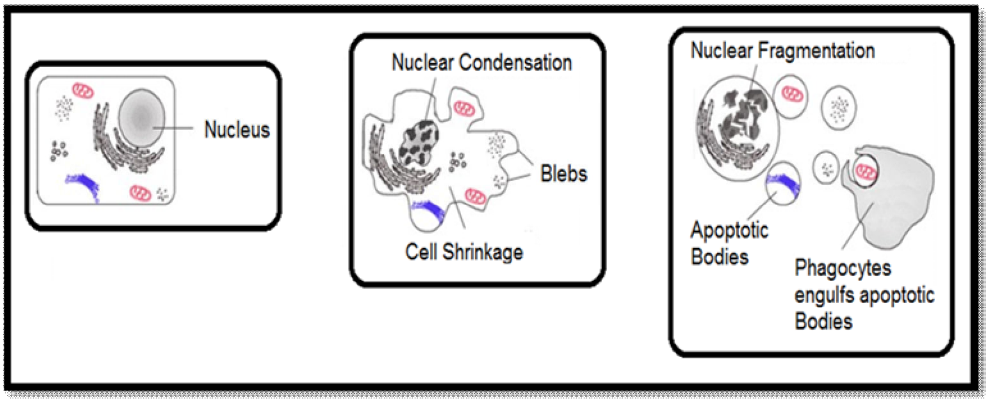

Figure 3- Shows Nuclear Condensation, Progressive Cell Shrinkage, Plasmamembrane blebbing, Apoptotic Bodies, Phagocytosis of apoptotic bodies or cell bodies.

These morphological alterations are results of characteristic molecular and biochemical events occurring in an apoptotic cell. Most importantly, the activation of proteolytic enzymes, which ultimately leads to the cleavage of chromosomal DNA into oligonucleosomal fragments as well as the cleavage of a multitude of specific protein substrates which usually determine the integrity and shape of the cytoplasm or organelles.

Apoptosis is a gene directed active process and regulated in a precise manner. As, it also associated with the activation of nucleases and the synthesis of RNA and proteins.

17.5. Molecular mechanisms of signalling pathways

This paragraph is meant to provide a general overview of basic apoptotic signalling pathways and of the molecular machinery responsible for the important signalling molecules and cellular structures, in which they are involved in the initiation, mediation, execution, and regulation of apoptosis.

The mechanisms of apoptosis involving an energy dependent cascade of molecular events. Thus, it is highly complex and sophisticated. To date, research indicates that there are two main apoptotic pathways: the extrinsic or death receptor pathway and the intrinsic or mitochondrial pathway. However, it is also evident, that the two pathways are inter-linked and that molecules in one pathway can influence the other.

17.5.1. The Extrinsic or Death Receptor Pathway

Extrinsic apoptosis pathway is triggered by extracellular signals delivered in the form of ligands binding to death receptors (DRs). In this pathway the stimulus for apoptosis is carried by an extracellular messenger protein called Tumor Necrosis Factor (TNF) or Death Receptor, which was named for its ability to kill tumor cells. It is produced by certain immune cells in response to adverse conditions, such as exposure to ionizing radiation, elevated temperature, viral infection, or toxic chemical agents such as those used in cancer chemotherapy. Members of TNF family share similar cyteine-rich extracellular domains and have a cytoplasmic domain of about 80 amino acids called the “death domain”. This death domain plays a critical role in transmitting the death signal from the cell surface to the intracellular signalling pathways.

TNF evokes its response by binding to a transmembrane receptor, TNFR1. TNFR1 is a member of a family of related “death receptors’ that mediate apoptosis. TNF receptor present in the plasma membrane as a preassembled trimer. The cytoplasmic domain of each TNF receptor subunit contains a segment of about 70 amino acids called a “death domain”. This death domain mediates protein-protein interactions. When TNF binds to a TNF receptor (TNFR1), this binding produces a change in conformation of the receptor’s death domain, which leads to the recruitment of two different cytoplasmic adaptor proteins (TRADD and FADD) and procaspase-8 to form a multiprotein complex at the inner surface of the plasma membrane.

The last proteins to join the complex that assembles at the inner surface of the plasma membrane are two procaspase-8 molecules. These proteins are called "procaspases" because each is a precursor of a caspase; it contains an extra portion that must be removed by proteolytic processing. The synthesis of caspases as proenzymes protects the cell from accidental proteolytic damage. After assembling in the complex, the two procaspase molecules cleave one another to generate an active caspase-8 molecule containing four polypeptide segment. Once caspase-8 is activated, the execution phase of apoptosis is triggered. Caspase-8 is described as an initiator complex that cleaves downstream (executioner) caspases that carry out the death sentence (Figure 4).

17.5.2. The Intrinsic Pathway

Intrinsic apoptosis is also known as mitochondrial apoptosis because it depends on factors released from the mitochondria. This pathway is activated by a vast array of cellular stresses, including growth factor deprivation, cytoskeletal disruption, Irreparable DNA damage, accumulation of unfolded proteins, extremely high concentrations of cytosolic Ca^{2+}, Oxidative stress (i.e. the production of large numbers of destructive free radicals), hypoxia, and many others. It can also be activated by developmental signals that instruct cells to die, such as hormones.

Activation of the intrinsic pathway is regulated by members of the Bcl-2 family of proteins. Bcl-2 family members can be subdivided into two groups:-
(i) Proapoptotic Members- Promotes apoptosis, e.g., Bad and Bax proteins. (ii) Antiapoptotic members- Protect cells from apoptosis. e.g., Bcl-x_L, Bcl-w, and Bcl-2. Bcl-2 was originally identified as a tumor-causing oncogene. It is further described that Bcl-2 acts as an oncogene by promoting survival of potential cancer cells that would otherwise die.

In the intrinsic pathway, stress stimuli activate certain proapoptotic members of the Bcl-2 family, such as Bax, which translocates from the cytosol to the outer mitochondrial membrane. The attachment of Bax to the outer mitochondrial membrane increases the permeability of that membrane and promotes the release of certain mitochondrial proteins, most notably cytochrome c, which resides in the intermembrane space. Release of proapoptotic mitochondrial proteins may be very crucial event that commits the cell to apoptosis. Cytochrome c forms part of a multiprotein complex by including several molecules of procaspase-9 in the cytosol, called the apoptosome. Activation of Procaspase-9 molecules do not require proteolytic cleavage; they are thought to become activated by simply joining with the multiprotein complex. Caspase-9 is also an initiator caspase (like Caspase-8, which is activated by the receptor-mediated pathway), that activates downstream executioner caspases, which bring about apoptosis (Figure 4).

Puma and Noxa are two members of the Bcl2 family that are also involved in pro-apoptosis. Puma plays an important role in p53-mediated apoptosis. It was shown that, in vitro, overexpression of Puma is accompanied by increased BAX expression, BAX conformational change, translocation to the mitochondria, cytochrome c release and reduction in the mitochondrial membrane potential. Noxa is also a candidate mediator of p53-induced apoptosis.

17.6. Execution Pathway

The extrinsic and intrinsic pathways both end at the point of the execution phase, considered the final pathway of apoptosis. It is the activation of the execution caspases that begins this phase of apoptosis. Execution caspases activate cytoplasmic endonuclease, which degrades nuclear material, and proteases that degrade the nuclear and cytoskeletal proteins. Caspase-3, caspase-6, and caspase-7 function as effector or “executioner” caspases, cleaving various substrates including cytokeratins, PARP, the plasma membrane cytoskeletal protein alpha fodrin, the nuclear protein NuMA and others, that ultimately cause the morphological and biochemical changes seen in apoptotic cells. Caspase-3 is considered to be the most important of the executioner caspases and is activated by any of the initiator caspases (caspase-8, caspase-9, or caspase-10). Caspase-3 specifically activates the endonuclease, Caspase Activated DNase (CAD). In proliferating cells CAD is complexed with its inhibitor, ICAD. In apoptotic cells, activated caspase-3 cleaves ICAD to release CAD. CAD then degrades chromosomal DNA within the nuclei and causes chromatin condensation. Caspase-3 also induces cytoskeletal reorganization and disintegration of the cell into apoptotic bodies.

Phagocytic uptake of apoptotic cells is the last component of apoptosis. Phospholipid asymmetry and externalization of phosphatidylserine on the surface of apoptotic cells and their fragments is the hallmark of this phase (Figure 4).

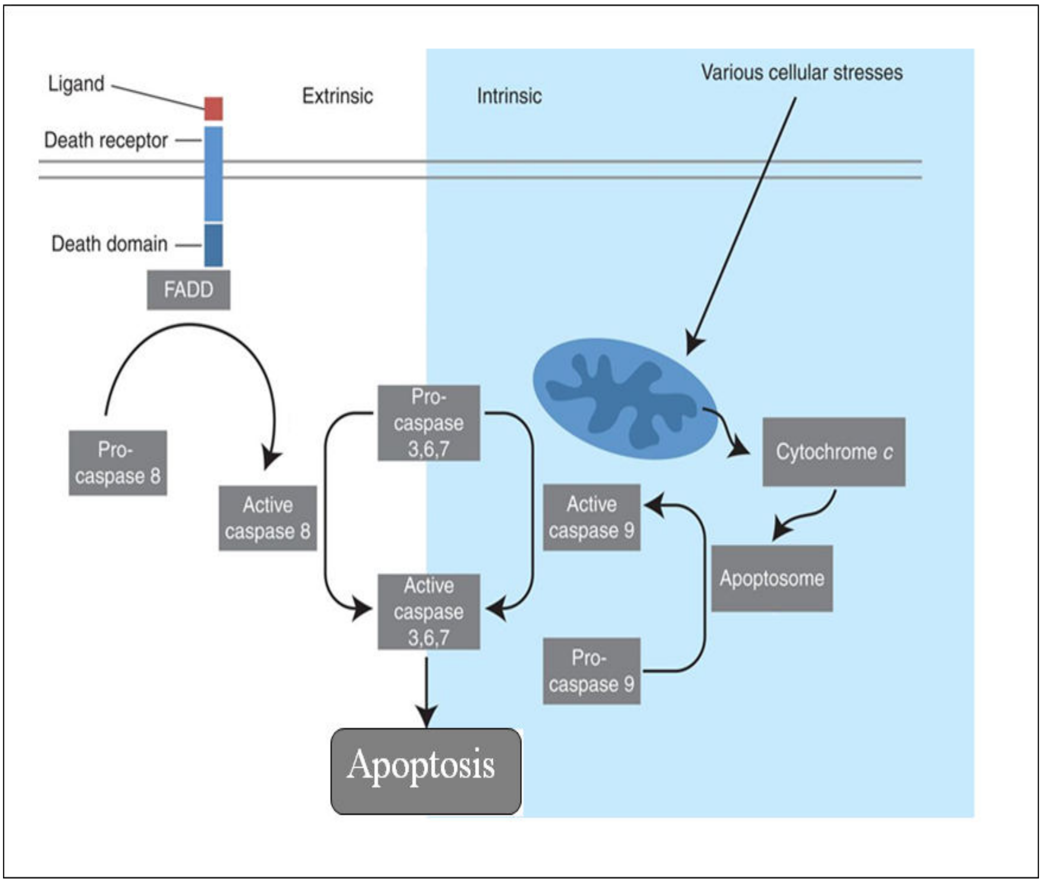

Figure 4:- Extrinsic and intrinsic pathways of apoptosis. The extrinsic apoptosis pathway is activated through the binding of a ligand to a death receptor, which in turn leads, with the help of the adapter proteins (FADD/TRADD), to recruitment, dimerization, and activation of caspase-8. Active caspase-8 then either initiates apoptosis directly by cleaving and thereby activating executioner caspase (-3, -6, -7), or activates the intrinsic apoptotic pathway to induce efficient cell death. The intrinsic or mitochondrial apoptosis pathway can be activated through various cellular stresses that lead to cytochrome *c* release from the mitochondria and the formation of the apoptosome, comprised of cytochrome *c*, ATP, and caspase-9, resulting in the activation of caspase-9. Active caspase-9 then initiates apoptosis by cleaving and thereby activating executioner caspases (Source- David R. McIlwain et al. Cold Spring Harb Perspect Biol 2013;5)

17.7. Ageing or Senescence

17.7.1. Introduction

Failing disease or injury, a multicellular organism dies from the process of aging or senescence (Ebert and Sussex, 1970), which takes different forms in different types of cell. Ageing procedure begins after the organism has attained sexual maturity and it ends lastly in the death of the organism. There is continued progressive decrease in the production rate with increasing age of the organism. Most animals undergo the process of ageing, which is also known as senescence. The branch of study dealing with old age and ageing is called Gerontology. Ageing varies from a few days to a few years or more. Man has an average life span of 100 years that is set by a group of death genes. Once the juvenile period, which is a period of active growth under hormonal influence, is completed and the organism enters the adult phase, growth is replaced by a metabolic equilibrium between anabolism and catabolism.

Some animals tend to escape ageing by evolving a rejuvenation process. Bryozoans are excellent examples, which get rid off ageing effects by discarding “brown bodies” and thus are able to rejuvenate a new life. No amount of improvement in sanitation, richness in diet or improvement of medical care facilities can increase the longevity of mammals.

Such improvements may simply increase the percentage of survivors at lower ages in the population. The process of ageing is the progressive decline in all vital activities of the organism that terminate in death goes on at different rates in animals of various species and in different individuals of the same species.

Although the life spans of individual cells do not appear to alter significantly. This means that not all dying cells are being replaced, and there is a loss of weight and loss of functions in tissues and organs; for instance, in animals the heart does not pump so much blood in a given time as it did when the individual was a young adult, the blood is not oxygenated so efficiently as it passes through the lungs, the actual blood volume diminishes, partly because tissues retain less water and partly because the production of red blood cells slows down, and so on. All of this means that a greater burden is thrown on the remaining cells.

Hormonal changes affecting adversely the functioning of various organs, the accumulation of waste material from various metabolic processes inside certain cells, loss of elasticity in elastic fibres, and an increase in the amount of collagen in connective tissues. These all changes plays and important role in aging.

At cellular level, the following processes are involved:

A. **Possible reduction** in functional efficiency of non-dividing highly specialized cells such as nerve cells, muscle cells, etc.

B. **Progressive stiffening** with age of the structural protein collagen which constitutes more than a third of all body proteins and serves as general binding substance of skin, muscular and vascular systems. It is also the substance of cartilage and tendons, it fills up the spaces between muscle fibres and between the cells of many organs, serving as the stabilizing fibre of connective tissue. In skin, a thick mating of collagen fibres gives the skin its toughness and plasticity.

   During ageing process collagen accumulates changes in the molecular structure that affects its integrity and function. The ageing of collagen may provide an objective index for determination of 'biological age' as distinguished from 'calendar age' of men and other animals. Once the fibres of collagen are laid down in the body they cannot be renewed.

   Collagen molecule consists of 3 strands wound around to form helices. During collagen ageing cross links increase in number between the different strands and different molecules.

C. **Limitation of cell division:** Hayflick (1968) showed that as population of human fibroblasts approaches the end of its lifetime, aberrations often crop up in the chromosomes. Chromosome aberrations and cell division peculiarities related to age have also been observed in leucocytes and in liver. In man several organs lose weight after middle age, which can be attributed to cell loss. The human brain weighs considerably less in old age than it does in middle age.

   Kidney also shows reduction in nephrons accompanying cell loss and the number of taste buds per papilla of tongue drops from 245 in young adults to 88 in aged. Animal age may also result from deterioration of the genetic program that orchestrates the development of cells. As time goes on, the following changes occur.

   - The DNA of dividing cells may become clouded with an accumulation of copying errors.

- The coding and decoding systems that govern the replication of DNA operates with high degree of accuracy, but the accuracy is not absolute.
- Certain enzymes involved in the transcription of information from DNA for the protein synthesis may deteriorate with age. All these events lead to loss of progression of cells as a result of ageing and eventually to the death of cells.

17.7.2. Cellular Changes during Ageing:-

Ageing causes changes in cells at numerous levels which can be

17.7.2.1. Morphological changes,
17.7.2.2. Physiological changes and
17.7.2.3. Subcellular changes.

17.7.2.1. Morphological changes:-The most obvious morphological changes occurring during ageing in cells may be as follows:

(i) **Decline in cell volume:** The cell undergoing ageing exhibits reduced cell volume. Reduced cell volume and cell death results in decreased weight of organs, thereby resulting in progressive decline of body weight.

(ii) **Accumulation of exhaustion pigment:** The exhaustion pigment **lipofuscin**, yellow pigment or brown degenerations are peroxidation byproducts of unsaturated membrane lipids (fatty acids) and denatured proteins of lysosomes. These are present in nerve and cardiac muscle cells and also in other cells of the body to a lesser degree.

(iii) **Nuclear Pyknosis:** With advancing age, the nucleus becomes shrunken and stains deeply. Such a nucleus is called pyknotic and the degenerative process is known as nuclear pyknosis.

(iv)**Formation of lipid vacuoles:** Ageing results in accumulation of small lipid vacuoles in the cytoplasm.

17.7.2.2. Physiological Changes:- Various physiological and biochemical changes occurring in the ageing cells are:

a) **Collagen and ageing:** Collagen, an essential basic protein present in the connective tissue becomes cross-linked and stiff with ageing.

b) **Calcium and ageing**: In the ageing cells, Ca++ ions are found to accumulate in the peripheral cytoplasm due to changes in the permeability of cellular membranes.

c) **DNA and Cellular ageing:** Loss of nuclear material and DNA damage progresses with age. Due to this, RNA synthesis and protein production also decline leading to cell loss with age.

d) **RNA and cellular ageing:** There are some evidences of quantitative age changes in the metabolism of individual RNA species. Decline in transcription may result from alterations in chromosome organization, specifically at the level of chromosomal proteins that complex with DNA to form chromatin.

e) **Protein synthesis and cellular ageing:** The synthesis of protein universally declines with age in all eukaryotic organisms. Ageing also causes decline in rRNA and alterations in tRNA (required for amino acid binding). Elongation factors necessary for stabilization and continued elongation of the polypeptide chain decrease with age. Post-translational modifications also occur during ageing. Other biochemical changes associated with ageing are-

- Increase in cholesterol and triglyceride level,
- Increase in Blood globulin levels,
- Decrease in alkaline and acid phosphatases,
- Decrease in cellular respiration and
- Increase in serum creatinine

17.7.2.3. Subcellular changes:- Various subcellular changes associated with ageing are:

a) **Plasma membrane:** The functional capacity of plasma membrane gets disturbed during ageing. Its permeability changes and Ca^{++} becomes accumulated in the membrane. Total lipids of membranes decrease with age. The cholesterol: phospholipid ratio in cellular membranes increase with age.

b) **Endoplasmic reticulum:** The amount of granular E. R. decrease in the cytoplasm of old cells due to ageing. In the nerves of older animals and human beings, there is decrease of Nissl granules (rRNA).

c) **Mitochondria: Reiner (1947) has reported that d**ue to ageing, the rate of carbohydrate metabolism (Krebs Cycle) is decreased. The Aging also affects glycolysis. Dampsey (1956) has shown that, the mitochondria are involved in the ageing process of the animals and in old tissues, the mitochondria become degenerated. In ageing cells, the rate of respiration in multicellular organisms becomes slow and they become somewhat dehydrated.

d) **Nucleus :** Nucleus remains unaltered in size in ageing cells. **Minot** (1970) has reported that the natural death of the cell is a consequence of cellular differentiation of which, the change in nucleo-cytoplasmic ratio acts as an important index for natural senescence and death. Incidence of loss of one X-chromosome in woman and Y-chromosome in man have been reported in ageing cells.

17.7.3. Ageing in Plants and Animals:-

From evolution point of view, it is known that those species having separate germ and somatic cell lines only exhibit senescence. Species producing by asexual means such as fission do not exhibit senescence due to natural selection operation. It has been suggested that some genes selected by Natural Selection for positive effect in early life may have negative effect in later years after reproductive activity has declined due to accumulation of deleterious traits that result in senescence.

17.7.3.1. Ageing in Plants:- Ageing and senescence in plants occur at various levels such as at cellular level, organ level, developmental level and at organism level.

17.7.3.2. Ageing in Animals:-Animals from protozoans to vertebrates exhibit ageing and senescence. Indefinite life span is found in those animals which exhibit asexual reproduction and continued growth or replacement of all body parts throughout life. This is related to genetic constitution of individuals that plays a role in ageing.

In mammals, a relationship also exists between the ratio of brain weight to body weight and life span and the proportion of life spent in the prereproductive stage and reproductive phase; the more delayed the onset of reproductive life, the longer the life span and the later the onset of senescence.

17.7.4. Ageing and organ systems:-

With ageing, changes occur in various organ systems of the body. The development of senescence is slow and progressive. It progresses at different rates in different systems and in different individuals, leading to a loss of reserve and increasing probability of organ system failure and death. Age related changes in organ systems are as follows:

17.7.4.1. Nervous System:- The changes includes atrophy of the brain and increase in size of brain ventricles, loss of brain weight (1400 gms at age 20 to 1334 gms at age 60), loss of white matter, shrinkage of dendrites, loss of nerve cells, accumulation of age pigment-lipofuscin, increase in cerebral amyloid, decrease in synaptic density in cerebellum, loss of cerebellar purkinje cells, decline in cerebellar integrative functions, decline in learning, decline in short term memory and recall from long term storage.

17.7.4.2. Sense organs:- The changes includes decrease in the number of taste buds, decline in olfactory sensitivity, reduction in sensory cells in nasal passages, occurrence of drooping eyelids, decline in lacrymal secretion, development of astigmatism, cataract and presbyopia, decrease in aperture of iris, retinal detachment, diminished fidelity of colour vision, physiological degeneration of auditory system resulting in bilateral loss of hearing, degeneration of vestibular system and increase in touch threshold.

17.7.4.3. Immune system:- The changes includes impairment of both cellular and humoral immunity, involution or regression of thymus gland, decline in T-cell function, increase in susceptibility to infections, increase in autoimmune diseases such as inflammation of thyroid, nerve endings and testes.

17.7.4.4. Endocrine system:- Decline in TSH, decline in synthesis of sex hormones from gonads and decrease in renin and aldosterone levels are the various changes.

17.7.4.5. Gastrointestinal system:- The changes include atrophy of oral mucosa and degeneration of oral connective tissue, hardening of tooth enamel, calcification of tooth pulp leading to tooth loosening, reduction in salivary secretion, reduction in peristaltic activity, atrophy of gastric mucosal lining and diminished gastric digestion, impairment of intestinal digestive and absorptive processes, loss of liver weight and decrease in number of hepatocytes per unit volume of liver, decreased motor **functions** in colon leading to frequent constipation and increase in colorectal cancer.

17.7.4.6. Blood vascular system:- The changes occurring includes diminution of heart muscle mass and increased fibrous tissue, increase in atrial volume, accumulation of lipofuscin pigment in heart muscles, degenerative calcification of aortic valves, increase in arterial intimal layer due to accumulation of smooth muscle cells, development of atherosclerosis and pulse and increase in systole, diastole and pulse pressure.

17.7.4.7. **Muscles and Bones:-** Atrophy of skeletal muscles, decrease in size and number of muscle fibres, decline in muscle tension, increase in osteoblast activity resulting in increased bone resorption, development of osteoporosis and loss of joint flexibility due to cross linking of collagen molecules are the various changes.

17.7.4.8. **Respiratory system:-** The changes are increase in volume of ducts decreasing gaseous exchange, increase in thickness of bronchial mucous gland layer, decrease in vital capacity of lungs, increase in dead space, diminution of diffusion capacity in lungs and respiration become progressively more difficult.

17.7.4.9. **Excretory system:-** The changes include decrease in weight and volume of kidney, loss of nephrons, decline in filtration rate, impairment of elimination of nitrogenous wastes, reduction in creatinine clearance, frequent and incontinence urination.

17.7.4.10. **Reproductive system and Sexual activity:-** The changes are menopause in female, atrophy of ovaries, enlargement of prostate glands in males, atrophy of testes, increased sexual arousal and capacity for orgasm in postmenopausal females and decrease in penile erection.

17.7.5. Theories on Ageing

Ageing is not just a natural loss of life but exact process of development, though vicious. A number of factors are accountable for the ageing procedure and these jointly act through a composite network of interacting positive and negative feedback system. The major theories proposed to explain ageing can be generally classified into two groups.

The first deals with ageing at the level of the cell, and is known as the cellular theory, and the second takes into account the whole body for understanding of the ageing process-the systemic theory or extracellular theory of ageing.

Various theories explaining ageing are:

17.7.5.1. **Neuroendocrine Theory:-** This theory was first proposed by Professor Vladimir Dilman and Ward Dean MD, this theory elaborates on wear and tear by focusing on the neuroendocrine system. This system is a complicated network of many biochemicals that govern the release of hormones which are altered by the hypothalamus (walnut sized gland; located in the brain).

The hypothalamus controls various chain-reactions to instruct other organs and glands to release their hormones etc. The hypothalamus also responds to the body hormone levels as a guide to the overall hormonal activity. But as we grow older the hypothalamus loses it precision regulatory ability and the receptors which uptake individual hormones become less sensitive to them. Accordingly, as we age the secretion of many hormones declines and their effectiveness (compared unit to unit) is also reduced due to the receptors down-grading. All the body activities are dependent on neurological and endocrine systems. Throughout the life, the loss of neurons and endocrine cells takes place. As a result, there occurs reduction in brain weight due to cell loss and loss of fluids and ground substance. Changes in endocrine functions result from cell loss and changes in receptors for hormones. Recent studies confirm that aging is hormonally regulated and that the evolutionarily conserved insulin/IGF-1 signaling (IIS) pathway plays a key role in the hormonal regulation of aging.

17.7.5.2. Immune System Theory: - The immune system is programmed to decline over time, which leads to an increased vulnerability to infectious disease and thus aging and death. It is well documented that the effectiveness of the immune system peaks at puberty and gradually declines thereafter with advance in age. For example, as one grows older, antibodies lose their effectiveness, and fewer new diseases can be combated effectively by the body, which causes cellular stress and eventual death.

This theory is based on two main aspects: -

a) Age dependent decline in the capacity of the immune system mainly thymus derived immunity (T-cell or cellular immunity) and

b) Autoimmunity – Immune system starts treating autologous tissues as foreign. These conditions lead to vulnerability to diseases and abnormalities, consequential from autoimmune response.

Definite diseases of older age are characterized by some degree of immune system dysfunction. These diseases comprise (i) cancer (failure of immune surveillance), (ii) Mature-onset diabetes (autoantibody action against insulin receptors, insulin and Islets of pancreas), (iii) Some vascular diseases and (iv) Autoimmune effects bring about changes in proteins such as collagen and introduces errors in transcriptions, translations, or post-translation fluctuations. Although direct causal relationships have not been established for all these detrimental outcomes, the immune system has been at least indirectly implicated.

17.7.5.3. Somatic Mutation Theory:- Mutations are the changes in the DNA of a cell. Somatic cell of the body of organisms develop spontaneous mutations. DNA damages occur continuously in cells of living organisms. However, most of these damages are repaired, some accumulate, as the DNA Polymerases and other repair mechanisms cannot correct defects as fast as they are apparently produced. In particular, there is evidence for DNA damage accumulation in non-dividing cells of mammals. Genetic mutations occur and accumulate with increasing age, causing cells to deteriorate and malfunction. In particular, damage to mitochondrial DNA might lead to mitochondrial dysfunction. The impaired DNA may render the cell defective in the production of essential enzymes resulting in the cell ageing or even cell death. Therefore, aging results from damage to the genetic integrity of the body's cells

17.7.5.4. Error and Fidelity Theory:- The ageing results from a decline in the fidelity of all biological components. Here Fidelity refers to true reproduction of proper proteins through transcriptions and translation. The decrease in fidelity of transcription or translation is called as error and is distinct from DNA – based mutations. Error in transcription or translation results in the addition of improper amino acids into the sequence comprising a particular protein.

17.7.5.5. Glycation theory:- The theory states that glucose acts as a mediator of ageing. The process involves non-enzymatic reactions that take place between reducing sugars and tissue proteins and nucleic acids. The end products of such reactions in case of proteins leads to dehydrated and rearranged unalterable structures referred to as advanced glycation end (AGE) products. Similar end products are produced between DNA and reducing sugars. Glycated proteins show loss of enzyme activity, inappropriated cross linking and decreased degradation of irregular proteins. Glycation of DNA, most usually uracil residues resulting by deamination of thymine, if not repaired by excision repair and uracil DNA glycosylase, can induce mutation. Hemoglobin, collagen, and lens proteins are those proteins that undergo glycation with age. Glycation of collagen may direct to elasticity changes in blood vessels, tendons and much of the connective tissue strain of body tissues.

17.7.5.6. Cross-linking theory:- This theory of aging was proposed by Johan Bjorksten in 1942. According to this theory, cross linked proteins are accumulated in damages cells and tissues. This accumulation may result in slowing down bodily processes and ultimately leads to aging. Recent studies show that cross-linking reactions are involved in the age related changes in the proteins.

17.7.5.7. Program restriction theory:- It is now well recognized that the genetic information depends on base sequences of DNA. Only small amount of the information in DNA is utilized by cells of various tissues. Only the sequences suitable for a particular tissue are transcribed and translated; the remaining DNA is turned off. The theory of program restriction states that ageing may be due to increased 'turn off' of DNA, leading to impaired capacity of the cell to transcribe essential RNAs including mRNAs. Though DNA segments may not be actually lost, chromatin structure seems to change with age in a way that favours restriction of DNA transcription. This might lead to a functional loss of portions of the gene library.

17.7.5.8. The Free Radical Theory: - This theory is now very famous. This theory is given by Denham Harman MD at the University of Nebraska in 1956. The term free radical describes any molecule that has an unpaired electron, and this property makes it reactive against many healthy molecules in a destructive way. Because the free radical molecule has an extra unpaired electron, it creates an extra negative charge. This unbalanced energy makes the free radical bind itself to another balanced molecule as it tries to pair with electrons. In so doing, the balanced molecule becomes unbalanced and thus a free radical itself. It is known that diet, lifestyle, drugs (eg. Tobacco and Alcohol) and radiation etc., are all accelerators of free radical production within the body. According to this theory superoxide and other free radicals cause damage to the macromolecular components of the cell, giving rise to accumulated damage causing cells, and eventually organs, to stop functioning. The macromolecules such as nucleic acids, lipids, sugars, and proteins are susceptible to free radical attack. Nucleic acids can get additional base or sugar group; break in a single- and double-strand fashion in the backbone and cross link to other molecules. The body does possess some natural antioxidants in the form of enzymes, which help to curb the dangerous build-up of these free radicals, without which cellular death rates would be greatly increased, and subsequent life expectancies would decrease. This theory has been bolstered by experiments in which rodents fed antioxidants achieved greater mean longevity. However, at present there are some experimental findings which are not agreed with this early proposal. Recent report shows that reactive oxygen species (ROS) signaling is probably the most important enzyme/gene pathway responsible for the development of cell senescence and organismal aging and that ROS signaling might be considered as further development of free radical theory of aging.

17.7.5.9. Telomere Shortening: - Telomeres are repeated DNA sequences at the ends of chromosomes. They are not replicated by DNA polymerase, and they will shorten at each cell division unless maintained by telomerase. Telomerase adds the telomere onto the chromosome at each cell division. Most mammalian somatic tissues lack telomerase, so it has been proposed that telomere shortening could be a "clock" that eventually prohibits the cells from dividing any more. However, there is no correlation between telomere length and the life span of an animal (humans have much shorter telomeres than mice), nor is there a correlation between human telomere length and a person's age. Telomerase-deficient mice do not show profound ageing defects. It has been suggested that telomere-dependent inhibition of cell division might serve primarily as a defense against cancer rather than as a kind of "ageing clock".

17.7 Summary

Apoptosis is a form of programmed cell death. It is a very orderly process during which the genome of the cell is broken down, the cell is fragmented into smaller pieces and the debris is consumed by nearby cells (phagocytes) that clean up the cell fragments.

- Major steps of apoptosis:
  - Cell shrinks
  - Cell fragments
  - Cytoskeleton collapses
  - Nuclear envelope disassembles
  - Cells release apoptotic bodies
- The initiation phase of apoptosis is started by extracellular or intracellular stress, such as low oxygen levels or DNA damage
- The execution phase of apoptosis is carried out by enzymes called caspases that cause DNA damage, re-arrange the cytoskeleton, and disrupt intracellular transport, cell division, and signal transduction.

  Pathways:-
- The extrinsic pathway is mediated by membrane receptors that respond to death signals by activating caspases.
- The intrinsic pathway or mitochondrial pathway is controlled by members of the Bcl-2 family, which can exhibit pro-apoptotic or anti-apoptotic activity. Holes are punched in the mitochondrial membrane and pro-apoptotic factors are released.

Ageing occurs in all animals and plants. It is evidenced by a decline in vital activities of life. The symptoms of ageing are clearly demarcated at cellular, organ and system levels including morphological, physiological and nuclear events. There is a clear relationship between average life span and ageing of an individual's life cycle. Numerous genetic and non-genetic theories are proposed to describe ageing which have also been discussed in the chapter.

17.8 Glossary

- **Apoptosis-** A type of orderly or programmed cell death in which the cell responds to certain signals by initiating a normal response that leads to the death of the cell. Death by apoptosis is characterized by overall compaction of the cell and its nucleus, the orderly dissection of the chromatin into pieces at the hands of a special DNA-splitting endonuclease, and the rapid engulfment of the dying cell by phatocytosis.

- **Autophagy-** The destruction of organelles and their replacement during which an organelle is surrounded by a membrane donated by the endoplasmic reticulum. The membrane surrounding the organelle then fuses with a lysosome.
- **Necrosis-** (from the Greek νέκρωσις "death, the stage of dying, the act of killing" from νεκρός "dead") It is a form of cell injury which results in the premature death of cells in living tissue by autolysis.
- **Extrinsic Pathway**- The *extrinsic pathway* of apoptosis refers to cell death induced by external factors that activate the death-inducing signaling complex.
- **Intrinsic Pathway-** The *intrinsic pathway* of apoptosis refers to cell death initiated by changes in mitochondria, also known as the *mitochondrial pathway* or *intracellular pathway* or intrinsic apoptosis.
- **Ageing**- It also spelled **aging**, is the process of becoming older. In the narrow sense, the term refers to biological ageing of human beings, animals and other organisms. In the broader sense, ageing can refer to single cells within an organism which have ceased dividing (cellular senescence) or to the population of a species (population ageing).

17.9 Self Learning Exercise

Section A- Objective type questions (With Answers)

1. Which cellular organs are involved in the initiation of the intrinsic pathway of apoptosis
   a. Endoplasmic Reticulum
   b. Lysosomes
   c. Peroxisomes
   d. Mitochondria **Ans. d.**

2. In which of the following situations would cells die by necrosis, not apoptosis?
   a. Removal of cells with damaged DNA that cannot be repaired

b. Removal of developing neurones that fail to make profitable connections with other cells
c. Removal of heart muscle cells damaged by oxygen depletion following cardiac Infarction
d. Removal of virus infected cells

Ans. c.

3. Which of the following are killed by the extrinsic apoptosis pathway?

a. Cells with damaged DNA.
b. Developing nerve cells that fail to make profitable connections.
c. Virus infected cells.
d. Irradiated cells. **Ans. c.**

4. Causes of necrosis includes

a. injury
b. cancer
c. infection
d. all of above **Ans. d**

5. The triggering of the intrinsic pathway of apoptosis involves a balance between pro-apoptotic and anti-apoptotic proteins. Which of the following is anti-apoptotic?

a. Bax
b. Bcl-2
c. Cytochrome c
d. Bad

Ans. b

6. Which of the following changes are common to ageing.

a. Slower reaction time for complex tasks
b. Declines in manual dexterity
c. A smaller range of motion
d. All of the above

Ans. d.

7. Study of aging is called:-

a. geronotology

b. histology
c. physiology
d. anthropology

Ans.a

8. Process of aging can be slowed by
   a. better nutrition
   b. improved living conditions
   c. adequate sleep
   d. all of above

Ans.d.

9. Changes is intracellular substances during aging includes
   a. increased cross linkages of collagen
   b. loss of elasticity in elastic tissues
   c. loss of resilience in connective tissue
   d. all of above

Ans.d

10. Signs of aging include
   a. loss of hair pigment
   b. dryness and wrinkling of skin
   c. forgetfulness
   d. all of above

Ans. d.

Section-B Short Answers types questions

1. Define Apoptosis.
2. Distinguish apoptosis and pathological cell death.
3. Define the phenomenon of aging or senescence.
4. Write notes on:-
   a) **S**ignificance of programmed cell death.
   b) Morphological changes during cell aging.
   c) Subcellular changes during cell aging.

d) Physiological changes in aging.

Section-C Long Answer Type Questions:-

1. Discuss the molecular mechanisms of signalling pathways during apoptosis.
2. Describe the process of aging.
3. Discuss different theories of the possible causes of senescence in detail.

17.10 References

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