Post-Graduate Degree Programme (CBCS)
in
ZOOLOGY
(M.Sc. Programme)

SEMESTER-III

Arthropod of Economic Importance,Concept of Biodiversity and Evolution

ZCORT-309

Self-Learning Material

DIRECTORATE OF OPEN AND DISTANCE LEARNING
UNIVERSITY OF KALYANI
Kalyani, Nadia
West Bengal, India

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Director's Message

Satisfying the varied needs of distance learners, overcoming the obstacle of distance and reaching the unreached students are the threefold functions catered by Open and Distance Learning (ODL) systems. The onus lies on writers, editors, production professionals and other personnel involved in the process to overcome the challenges inherent to curriculum design and production of relevant Self Learning Materials (SLMs). At the University of Kalyani a dedicated team under the able guidance of the Hon'ble Vice-Chancellor has invested its best efforts, professionally and in keeping with the demands of Post Graduate CBCS Programmes in Distance Mode to devise a self-sufficient curriculum for each course offered by the Directorate of Open and Distance Learning (DODL), University of Kalyani.

Development of printed SLMs for students admitted to the DODL within a limited time to cater to the academic requirements of the Course as per standards set by Distance Education Bureau of the University Grants Commission, New Delhi, India under Open and Distance Mode UGC Regulations, 2020 had been our endeavour. We are happy to have achieved our goal.

Utmost care and precision have been ensured in the development of the SLMs, making them useful to the learners, besides avoiding errors as far as practicable. Further suggestions from the stakeholders in this would be welcome.

During the production-process of the SLMs, the team continuously received positive stimulations and feedback from Professor (Dr.) Manas Kumar Sanyal, Hon'ble Vice-Chancellor, University of Kalyani, who kindly accorded directions, encouragements and suggestions, offered constructive criticism to develop it within proper requirements. We gracefully, acknowledge his inspiration and guidance.

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Their persistent and coordinated efforts have resulted in the compilation of comprehensive, learner-friendly, flexible texts that meet the curriculum requirements of the Post Graduate Programme through Distance Mode.

All the Self Learning Materials are self writing and collected from e-book, journals and websites.

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HARD CORE THEORY PAPER (ZCORT- 309)

Group A (Arthropod of Economic Importance)				
Module	**Unit**	**Content**	**Credit**	**Page No.**
ZCORT–309 (Arthropod of Economic Importance)	I	Insect pests: Morphology, bionomics and control of i) Stored grains: Stored rice grain moth (*Corcyra cephalonica*) and stored pulse beetle (*Callosobruchus chinensis*)	**3**	
	II	Insect pests: Morphology, bionomics and control of ii) Field insect pests: Fall army worm (*Spodoptera frugiperda*), cardamom capsule borer (*Conoganthes punctiferalis*), jute semi looper (*Anomis sabulifera*).		
	III	Pest management: Mechanical; Chemical		
	IV	Pest management: Biological; Integrated.		
	V	Lac culture: Life-history of lac insect, culture method, lac processing, lac products, natural enemies of lac insect and their control.		
	VI	Sericulture: Indigenous races, pure races and commercial races of mulberry silk moth; rearing of mulberry silk moth		
	VII	Parasitic insects and Acarines: a) General remarks on *Phlebotomous* and *Glossina* in relation to morphology, habit, habitat, life cycle and disease caused by them, mode of transmission.		
	VIII	Parasitic insects and Acarines: b) General remarks on *Tabanus* and head louse in relation to morphology, habit, habitat, life cycle and disease caused by them, mode of transmission.		

	IX	Parasitic insects and Acarines: c) General remarks on mites in relation to morphology, habitat, life cycle and diseases caused by them.		
	X	Parasitic insects and Acarines: d) General remarks on ticks in relation to morphology, habitat, life cycle and diseases caused by them		
ZCORT-309 (Concept of Biodiversity and Evolution)	**Group B (Concept of Biodiversity and Evolution)**			
	XI	Levels of species diversity and relationship; geographic distribution of biological diversity; biological hotspots; measuring biodiversity; interrelationship between diversity measures; pattern of local and regional biodiversity.	**3**	
	XII	Threats to species diversity; natural and human induced threats and vulnerability of species extinction; Red data book; rarity, endemism		
	XIII	Effective and minimum viable population, fragmentation of population; problems of genetic diversity; bottleneck; genetic drifts; inbreeding depression.		
	XIV	Biodiversity Resource Management, values and uses of biological diversity as source of foods, drugs and medicines.		
	XV	Theories on relation between biodiversity and ecosystem function i. Species Complementarity ii. Sampling effect iii. Redundancy.		
	XVI	The economics of biodiversity and ecosystem function.		
	XVII	Landscape Ecology: a) Theories in landscape ecology. Hierarchy theory and the structure of the landscape, Percolation theory, The systems source sink, b) Scale and landscape, Scaling the landscape, Change of scale perception. Importance of parameters at different scales,		
	XVIII	Landscape Ecology: c) Processes in the landscape:		

		Disturbance, Fragmentation, Landscape connectivity, Corridors, d) Methods in landscape ecology, Spatial data processing, fractal geometry approach, urban ecology.		
	XIX	Remote sensing in landscape ecology, Geographic Information System, Spatially explicit population models (SEPM).		
	XX	Organic evolution: concept and evidences (comparative anatomy, embryology, biogeography, palaeontology, genetics, biochemistry and physiology).		
	Total counseling session 18hrs.			

UNIT I

Insect pests: Morphology, bionomics and control of Stored grains: Stored rice grain moth (*Corcyra cephalonica*) and stored pulse beetle (*Callosobruchus chinensis*)

Objective:

In this unit we will discuss about Morphology, bionomics and control of stored grains: Stored rice grain moth (*Corcyra cephalonica*) and stored pulse beetle (*Callosobruchus chinensis*)

I. Stored rice grain moth (*Corcyra cephalonica*)

Introduction:

Corcyra cephalonica commonly called as rice meal moth or rice moth is a pest of stored foods, *viz.,* cereals, cereal products, oilseeds, pulses, dried fruits, nuts and spices. The rice moth can be considered the Indian meal moth of the tropics. It is found in Hawaii and occasionally in some southern U.S. ports. It is much less common on the mainland than the Almond moth, (*Ephestia cautella*), which it is often misidentified. The larvae are general feeders and prefer warm climates and occur commonly in the equatorial regions of Asia, Africa, and Caribbean.

The rice moth populations develop well in hot damp or dry (> 20% rh) areas. These moths can infest mills and storage areas simultaneously with Almond moths.

The moth is usually seen in large numbers on walls, poles, or containers where grains are stored. The larvae are exceptionally good at producing "paper thick" webbing for its cocoons. The caterpillars produce a large amount of frass (in which they hide) compared to other stored food moths. This material can attract other stored food pests such as Flour beetles (*Tribolium* spp).

<u>Taxonomy:</u>

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Uniramia
Class: Insecta
Order: Lepidoptera
Family: Pyralidae
Genus: *Corcyra*
Species: *cephalonica*

Morphology:

The adult moth is grey, often with darker spots or venation on the wings; the under wings are off white. The wing span is 20-23 mm. The tips of the wings are more rounded than those of the *Ephestia* spp. moths. The hind-wings are pale-buff, and the fore-wings are mid-brown or greyish-brown with thin vague lines of darker brown colour along the wing veins. The larva of the rice moth will grow to 15 mm long and are white or cream in colour. The body is covered with fine hairs. A good clue that rice moth larvae are present is the excessively thick layers of webbing. The adults are small. The males are smaller than the females

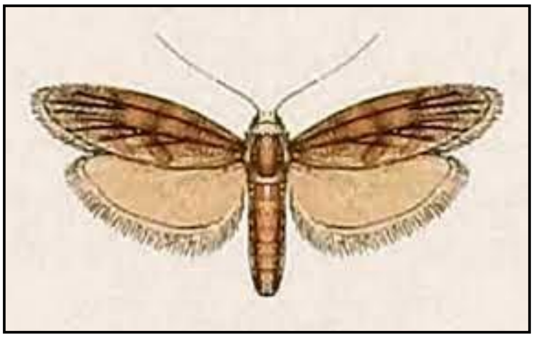


Fig: Adult Rice grain moth (*Corcyra cephalonica*)

Life cycle:

Adults light greyish-brown in colour, 12 mm long and with a wing span of about 15 mm, without any markings on the wings but veins are slightly darkened. Head bears a projected tuft of scales. Moths are short lived but realize a fecundity of 150—200 eggs per female within a few days after emergence.

Eggs are laid anywhere, on the grains, among grains, on the containers or on any surface near the grains, either singly or in clusters. Eggs are whitish, oval in shape, 0.5 mm long and having an incubation period of 4-5 days. Tiny larva after hatching is creamy-white, with a prominent head. It moves about actively and feeds on broken grains for sometime and then starts spinning web to join grains.

Full grown larva is pale whitish in colour, 15 mm long with short scattered hairs and no markings on body. Larval period is 25-35 days in summer and may be extended in winter. Pupation takes place inside an extremely tough, opaque whitish cocoon that is surrounded by webbed grains. Pupal period is about 10 days but may extend to 40-50 days to tide over winter moths. Moths commence mating and egg laying immediately after emergence.

Damage symptoms: The larvae alone damage the grains of rice and maize by feeding under silken webs. When infestation is high, the entire stock of grains may be converted into a webbed mass. Ultimately, a characteristic foul odour develops and the grains are rendered unfit for human consumption.

Bionomics:

Bionomics is that part of biology which deals with the relationships of a given species and its environment. The rice moth is active from· March to November. It passes winter in the larval stage. The moth laid eggs singly or in groups of 3-5 each on the grains, bags and on other objects in the godowns. A single female lay 62-150 eggs during its life-span of 24 days. The eggs hatch in 4-7 days and the larvae under silken web-like shelters, preferring the partially damaged grains. They are full-fed in 21-41 days, after which they make silken cocoons among the infested grains. The pupal stage lasts 9-14 days and the adults live for - one week. They complete life-cycle in 33-52 days and the pest completes approximately 6 generations in a year.

Prevention and control:

a. Cultural Control and Sanitary Methods:

Good store hygiene plays an important role in limiting infestation by *C. cephalonica*. The removal of infested residues from last season's harvest is essential as is general hygiene in stores, such as ensuring that all spillage is removed and cracks and crevices filled. Infestations may also be limited by the storage of good-quality grains such as whole cereals with fewer broken grains and foreign matter or milled rice with a high degree of milling (at least 95%) and few broken grains.

b. Plant Extracts:

Vitex negundo leaf powder, neem leaf powder and neem oil were the most effective of a range of plant products tested for efficacy against *C. cephalonica* in stored ground nuts. Four neem products (azadirachtin, azadirachtin-iodine, neem seed kernel extract and neem oil) were tested on the eggs and larvae of *C. cephalonica* for ovicidal, larvicidal, feeding deterrent growth regulatory and anti-fertility activity. Age, toxicity, mortality, concentration and growth inhibition established a dose-response relationship whereas feeding inhibition and growth disruption were independent events. Petroleum ether extracts (1.5%) of *Azadirachta indica*, *Erythrina indica* and *Piper nigrum* and *Pachyrhizuserosus* (at 2%) and methanol extracts (2%) of *A. indica* and *P. nigrum* prevented egg hatching in *C. cephalonica* 6 days after treatment. Leaf extracts of *Ricinus communis*, *Lawsonia inermis*, *Acacia nilotica*, *Cassia fistula*, *Eucalyptus rudis, Dalbergia sissoo* and *Parthenium hysterophorus* were tested for ovicidal activity against *C. cephalonica*. Leaf extracts of *Ricinus communis* (100%) produced maximum (89.5%) mortality, with lowest mortality (42.1%) exhibited by *P. hysterophorus*. Oil from sweet flag (*Acorus calamus*) was found to repel 10-day-old larvae of *C. cephalonica* at 0.1-0.5%. Oils from clove, cedar wood, citronella and eucalyptus were also effective.

c. Chemical Control:

Fumigation is one of the most effective ways of killing all stages of this insect in commodities and buildings. Fogging with a 0.5% pyrethrin is recommended only for knocking down exposed adult stages. Use of longer lasting synthetic pyrethroid and insect growth regulators in a fog will give superior results.

II. Stored pulse beetle (*Callosobruchus chinensis*)

Callosobruchus chinensis is a common species of beetle found in the bean weevil subfamily, and is known to be a pest to many stored legumes. It is commonly known as the adzuki bean weevil. Other common names include the pulse beetle, Chinese bruchid and cowpea bruchid. This species has a very similar lifestyle and habitat to *Callosobruchus maculatus* and their identities are often mistaken for each other. This beetle is a common pest targeting many different species of stored legumes and it is distributed across the tropical and subtropical regions of the world. *C. chinensis* is one of the most damaging crop pests to the stored legume industry due to their generalized legume diets and wide distribution.

Taxonomy:

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Uniramia
Class: Insecta
Order: Coleoptera
Family: Bruchidae
Genus: *Callosobruchus*
Species: *chinensis*

Distribution: Cosmopolitan in the tropics and subtropics of the world. A closely related species, *Callosobruchus maculatus* is found existing along with *chinensis.* Adults of the former species are elongated and darker and posterior part of the abdomen is exposed.

Morphology: The female is about 3-3.5 mm in length; the elytra are red-brown with yellow makings, antennae and legs yellow, female antennae serrate, those of male pectinate. Larva yellowish- white with a brown head and reduced legs, about 5 mm long. Several geographic strains of this species are known whose morphology is slightly different.

Figure: External morphology of *Callosobruchus chinensis*

Host plants:

Beans and peas, especially chick-peas with smooth, spherical pods.

Life cycle:

Adult beetle is 3-4 mm long, female being larger, brownish in colour, broader at shoulders and rounded posteriorly. There are dark patches on elytra and thorax. Adults show sexual dimorphism. Males possess deeply emarginated or indented eyes and prominently serrate antennae, while in female these characters are not distinctly marked.

In females tip of abdomen is exposed while in males it is covered by elytra. They are active beetles and readily fly when disturbed. Fecundity is about 100 eggs per female. Eggs are whitish, elongated and stuck on the grains or on pods and sometimes on the surface of the container. Incubation period is 3-6 days. Grubs are scarabeiform or eruciform, plump and with short legs and yellowish in colour.

First instar larvae bear functional legs and a pair of thoracic plates to facilitate boring into the seeds. They feed on the inner contents of the grain and may damage several grains during development. Larval period may vary between 12 and 20 days. Pupation takes place inside the grain and pupa is dark brown in colour. Occasionally pupation may take place outside the grain in a cocoon made of excretory matter. Completion of life cycle takes 4-5 weeks and there may be 6-7 overlapping generations in a year.

Economic importance:

The Adzuki beetle is a major pest of stored lentils. Pod infestation can start in the field before harvest, the pest thus gaining entrance into storage bins. It may cause substantial damage, coming to over 80% losses in weight and in germination rates. Infested seeds are less nutritious and unfit for humans.

Damage

The adult and grub feed on the grain by making a small hole. Infested stored seed can be recognized by the white eggs on the seed surface and the round exit holes with the 'flap' of seed coat.

A. Cultural Control

i. Periodical exposure of the grain to sun helps to check infestations.
ii. Dry the pods to optimum kernel moisture level of about 7 %.
iii. Store the pods in polythene-lined gunny bags and fill the top surface of the bag with a layer of 3 cm ht. sand.
iv. Mouth of bags should not be stitched or closed to avoid germination loss.
v. Care should be taken to avoid breakage
vi. Broken seeds should not be stored for long periods.
vii. Dust an inert substance such as ABCD (attapulgite-based clay dust)

B. Chemical Control

i. Dip the gunny bags in 10% malathion solution.
ii. Apply E.D.B. ampulses @ 3 ml/q of seed in air tight storage structure.
iii. Fumigation with aluminum phosphide protects the seed without affecting the viability.

C. Mechanical Control

i. Dip the old gunny bags in boiled water for 15 minutes.

D. Biological Control

i. Coat the seed with small quantities of vegetable oil or mix neem leaves in the stored grain.

Probable Questions:

1. Briefly describe the morphological features of *Corcyra cephalonica.*
2. Describe the life cycle of *Corcyra cephalonica.*
3. How *Corcyra cephalonica* can be controlled?
4. Briefly describe the morphological features of *Callosobruchus chinensis*
5. Describe the life cycle of *Callosobruchus chinensis*
6. How *Callosobruchus chinensis* can be controlled?

Suggested Readings:

1. The Insects by Chapman
2. Modern Entomology by D.B. Thembare
3. The Insects by Gullan and Carnston
4. Introduction to Economic Zoology by Sarkar, Kundu and Chaki.
5. A textbook of Economic Zoology by Aminul Islam

UNIT II

Insect pests: Morphology, bionomics and control of field insect pests: Fall army worm (*Spodoptera frugiperda*), cardamom capsule borer (*Conoganthes punctiferalis*) and jute semi looper (*Anomis sabulifera*)

Objective:

In this unit we will discuss about Morphology, bionomics and control of field insect pests: Fall army worm (*Spodoptera frugiperda*), cardamom capsule borer (*Conoganthes punctiferalis*) and jute semi looper (*Anomis sabulifera*)

I. Fall army worm (*Spodoptera frugiperda*)

Introduction:

The fall armyworm, *Spodoptera frugiperda* is a species in the order Lepidoptera and one of the species of the fall armyworm moths distinguished by their larval life stage. This pest is native to the tropical regions of the western hemisphere from the United States to Argentina. It normally overwinters successfully in the United States only in southern Florida and southern Texas. The fall armyworm is a strong flier, and disperses long distances annually during the summer months. It is recorded from virtually all states east of the Rocky Mountains; however, as a regular and serious pest, its range tends to be mostly the southeastern states. In 2016 it was reported for the first time in West and Central Africa, so it now threatens Africa and Europe.

However, the development of economically damaging populations depends on a number of factors such as; cropping practices, date of planting, insect migration patterns, parasites and predators, weather conditions, etc. Fall armyworm moths are attracted to extremely late planted corn, which normally can sustain considerable damage from this pest.

Taxonomy:

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Uniramia
Class: Insecta
Order: Lepidoptera
Family: Noctuidae
Genus: *Spodoptera*
Species: *frugiperda*

Morphology:

The fall armyworm moth has dark gray, mottled forewings with light and dark splotches, and a noticeable white spot near the extreme end of each. The adult moths are 32 to 40 millimetres ($1+^1/_4$ to $1+^1/_2$ in) wing tip to wing tip, with a brown or gray forewing, and a white hindwing. There is slight sexual dimorphism, with males having more patterns and a distinct white spot on each of their forewings. Newly hatched larvae are green in color and move in a looping motion. Fall armyworm larvae are smooth-skinned and vary in color from light tan or green to nearly black. They have three yellow-white hairlines down their backs. On each side of their bodies and next to the yellow lines is a wider dark stripe. Next to that is an equally wide, wavy, yellow stripe, splotched with red. Full-grown larvae are about 1-1/2 inches (38 mm) long.

Fig 1. Typical adult male fall armyworm, *Spodoptera frugiperda* (J.E. Smith). Photograph by Lyle J. Buss, University of Florida.

Fig 2 . Typical adult female fall armyworm, *Spodoptera frugiperda* (J.E. Smith). Photograph by Lyle J. Buss, University of Florida.

Life cycle:

The life cycle is completed in about 30 days during the summer, but 60 days in the spring and autumn, and 80 to 90 days during the winter. The number of generations occurring in an area varies with the appearance of the dispersing adults. The ability to diapause is not present in this species. The number of generations is dependent on the place and season of a year.

- **Egg:** The egg is dome shaped; the base is flattened and the egg curves upward to a broadly rounded point at the apex. The egg measures about 0.4 mm in diameter and 0.3 mm in height. The number of eggs per mass varies considerably but is often 100 to 200, and total egg production per female averages about 1500 with a maximum of over 2000.

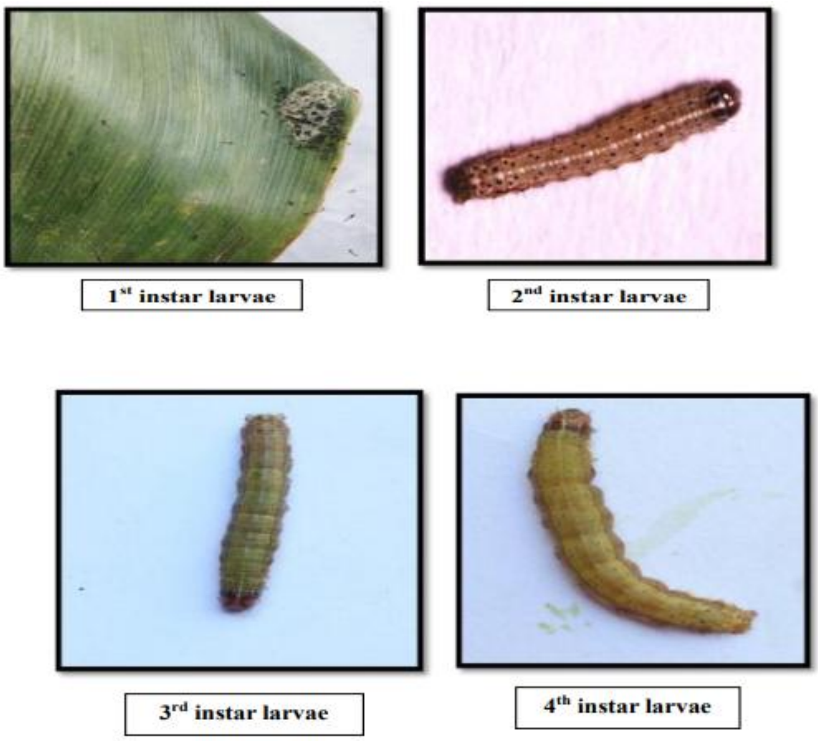
Fig 3. Egg mass of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith). Photograph by James Castner, University of Florida.

The eggs are sometimes deposited in layers, but most eggs are spread over a single layer attached to foliage. The female also deposits a layer of grayish scales between the eggs and over the egg mass, imparting a furry or moldy appearance. Duration of the egg stage is only two to three days during the summer months.

- **Larvae:** There usually are six instars in fall armyworm. Head capsule widths are about 0.35, 0.45, 0.75, 1.3, 2.0, and 2.6 mm, respectively, for instars 1 to 6. Larvae attain lengths of about 1.7, 3.5, 6.4, 10.0, 17.2, and 34.2 mm, respectively, during these instars.

Young larvae are greenish with a black head, the head turning orangish in the second instar. In the second, but particularly the third instar, the dorsal surface of the body becomes brownish, and lateral white lines begin to form. In the fourth to the sixth instars the head is reddish brown, mottled with white, and the brownish body bears white subdorsal and lateral lines. Elevated spots occur dorsally on the body; they are usually dark in color, and bear spines. The face of the mature larva is also marked with a white inverted "Y" and the epidermis of the larva is rough or granular in texture when examined closely. However, this larva does not feel rough to the touch, as does corn earworm, *Helicoverpa zea* (Boddie), because it lacks the microspines found on the similar-appearing corn earworm. In addition to the typical brownish form of the fall armyworm larva, the larva may be mostly green dorsally. In the green form, the dorsal elevated spots are pale rather than dark. Larvae tend to conceal themselves during the brightest time of the day. Duration of the larval stage tends to be about 14 days during the summer and 30 days during cool weather. Mean development time was determined to be 3.3, 1.7, 1.5, 1.5, 2.0, and 3.7 days for instars 1 to 6, respectively, when larvae were reared at 25ºC (Pitre and Hogg 1983).

Fig 4. Head capsule of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) showing light-colored inverted "Y" on front of head. Photograph by Lyle J. Buss, University of Florida.



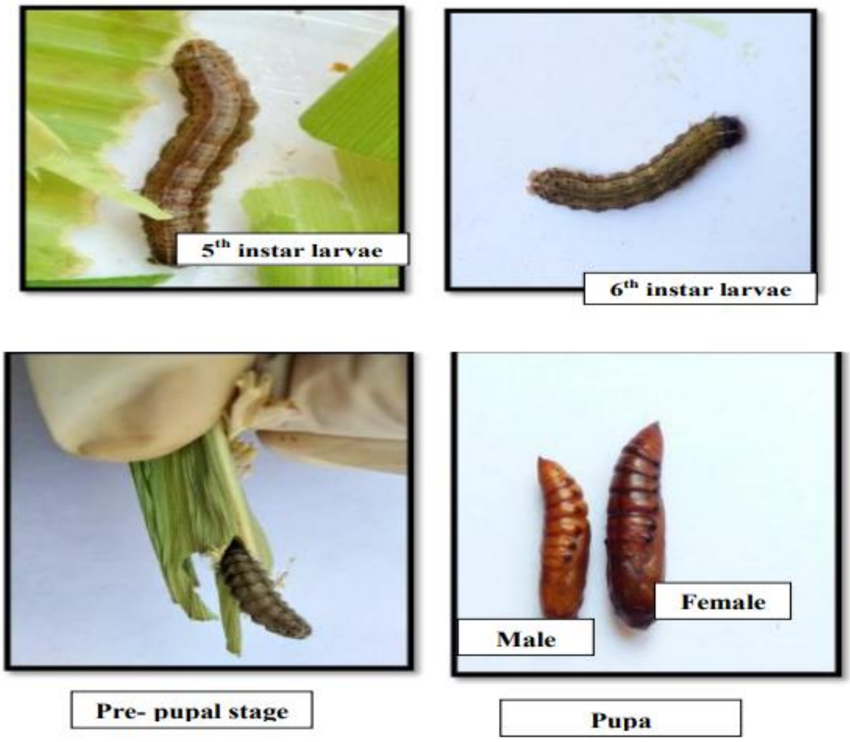


Fig 5. Different larval stages of fall army worm, *Spodoptera frugiperda* (by Paul N and Deole S, Int. J. Curr. Microbiol. App. Sci (2020) 9(9): 1732-1738)

- **Pupa:** Pupation normally takes place in the soil, at a depth 2 to 8 cm. The larva constructs a loose cocoon, oval in shape and 20 to 30 mm in length, by tying together particles of soil with silk. If the soil is too hard, larvae may web together leaf debris and other material to form a cocoon on the soil surface. The pupa is reddish brown in color, and measures 14 to 18 mm in length and about 4.5 mm in width. Duration of the pupal stage is about eight to nine days during the summer, but reaches 20 to 30 days during the winter in Florida. The pupal stage of fall armyworm cannot withstand protracted periods of cold weather. For example, Pitre and Hogg (1983) studied winter survival of the pupal stage in Florida, and found 51 percent survival in southern Florida, but only 27.5 percent survival in central Florida, and 11.6 percent survival in northern Florida.

- **Adult:** The moths have a wingspan of 32 to 40 mm. In the male moth, the forewing generally is shaded gray and brown, with triangular white spots at the tip and near the center of the wing. The forewings of females are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of gray and brown. The hind wing is iridescent silver-white with a narrow dark border in both sexes. Adults are nocturnal, and are most active during warm, humid evenings. After a preoviposition period of three to four days, the female normally deposits most of her eggs during the first four to five days of life, but some oviposition occurs for up to three weeks. Duration of adult life is estimated to average about 10 days, with a range of about seven to 21 days.

Host Plants

This species seemingly displays a very wide host range, with over 80 plants recorded, but clearly prefers grasses. The most frequently consumed plants are field corn and sweet corn, sorghum, Bermudagrass, and grass weeds such as crabgrass, *Digitaria* spp. When the larvae are very numerous they defoliate the preferred plants, acquire an "armyworm" habit and disperse in large numbers, consuming nearly all vegetation in their path.

Field crops are frequently injured, including alfalfa, barley, Bermudagrass, buckwheat, cotton, clover, corn, oat, millet, peanut, rice, ryegrass, sorghum, sugarbeet, Sudangrass, soybean, sugarcane, timothy, tobacco, and wheat.

Among vegetable crops, only sweet corn is regularly damaged, but others are attacked occasionally. Other crops sometimes injured are apple, grape, orange, papaya, peach, strawberry and a number of flowers. Weeds known to serve as hosts include bentgrass, *Agrostis* sp.; crabgrass, *Digitaria* spp.; Johnson grass, *Sorghum halepense*; morning glory, *Ipomoea* spp.; nutsedge, *Cyperus* spp.; pigweed, *Amaranthus* spp.; and sandspur, *Cenchrus tribuloides*.

Damage

Larvae cause damage by consuming foliage. Young larvae initially consume leaf tissue from one side, leaving the opposite epidermal layer intact. By the second or third instar, larvae begin to make holes in leaves, and eat from the edge of the leaves inward. Feeding in the whorl of corn often produces a characteristic row of perforations in the leaves. Larval densities are usually reduced to one to two per plant when larvae feed in close proximity to one another, due to cannibalistic behavior.

Fig 6. Corn leaf damage caused by the fall armyworm, *Spodoptera frugiperda* (J.E. Smith). Photograph by Paul Choate, University of Florida.

Older larvae cause extensive defoliation, often leaving only the ribs and stalks of corn plants, or a ragged, torn appearance. Larvae also will burrow into the growing point (bud, whorl, etc.), destroying the growth potential of plants, or clipping the leaves. In corn, they sometimes burrow into the ear, feeding on kernels in the same manner as corn earworm, *Helicoverpa* zea. Unlike corn earworm, which tends to feed down through the silk before attacking the kernels at the tip of the ear, fall armyworm will feed by burrowing through the husk on the side of the ear.

Management

i. **Sampling:** Moth populations can be sampled with blacklight traps and pheromone traps; the latter are more efficient. Pheromone traps should be suspended at canopy height, preferably in corn during the whorl stage. Catches are not necessarily good indicators of density, but indicate the presence of moths in an area. Once moths are detected it is advisable to search for eggs and larvae. A search of 20 plants in five locations, or 10 plants in 10 locations, is generally considered to be adequate to assess the proportion of plants infested. Sampling to determine larval density often requires large sample sizes, especially when larval densities are low or larvae are young, so it is not often used.

ii. **Insecticides:** Insecticides are usually applied to sweet corn in the southeastern states to protect against damage by fall armyworm, sometimes as frequently as daily during the silking stage. In Florida, fall armyworm is the most important pest of corn. It is often necessary to protect both the early vegetative stages and reproductive stage of corn. Because larvae feed deep in the whorl of young corn plants, a high volume of liquid insecticide may be required to obtain adequate penetration. Insecticides may be applied in the irrigation water if it is applied from overhead sprinklers. Granular insecticides are also applied over the young plants because the particles fall deep into the whorl. Some resistance to insecticides has been noted, with resistance varying regionally.

iii. **Cultural techniques:** The most important cultural practice, employed widely in southern states, is early planting and/or early maturing varieties. Early harvest allows many corn ears to escape the higher armyworm densities that develop later in the season (Mitchell 1978). Reduced tillage seems to have little effect on fall armyworm populations (All 1988), although delayed invasion by moths of fields with extensive crop residue has been observed, thus delaying and reducing the need for chemical suppression (Roberts and All 1993).

iv. **Host plant resistance:** Partial resistance is present in some sweet corn varieties, but is inadequate for complete protection.

v. **Biological control:** Although several pathogens have been shown experimentally to reduce the abundance of fall armyworm larvae in corn, only *Bacillus thuringiensis* presently is feasible, and success depends on having the product on the foliage when the larvae first appear. Natural strains of *Bacillus thuringiensis* tend not to be very potent, and genetically modified strains improve performance.

II. Cardamom capsule borer (*Conoganthes punctiferalis*)

Taxonomy

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Uniramia
Class: Insecta
Order: Lepidoptera
Family: Crambidae
Genus: *Conoganthes*
Species: *punctiferalis*

Identification

- **Egg**: is pink, oval, flat and lays singly or in group on the tender part of the plant
- **Larva:** is long, pale greenish with a pinkish was dorsally, head and pro-thoracic shield brown in colour and body covered with minute hairs arising on wards.
- **Pupa**: Pupation takes place in lose silken cocoon in larval tunnel.
- **Adult:** is a medium sized moth; the wings are pale yellowish with black spots on the wings.

Fig 7: Adult structure of *Conoganthes punctiferalis*

Symptoms of Damage

- Early stage of the larva bores the unopened leaf buds and feeds on the leaf tissue.
- They also bore the panicles leading to drying up of the portion from the affected spot

- Immature capsules and feed on the young seeds inside rendering the capsules empty.
- Late stage larvae bore the pseudostem and feed the central core of the stem
- Resulting in drying of the terminal leaf and thus produce characteristic 'dead heart' symptom.
- Oozing out of frass material at the point of tunnelling is the indication for the presence of larva inside the plant parts.
- The incidence of this pest is noticed throughout the year but they occur in enormous number in four periods, December-January, March-April, May-June and September-October and their abundance synchronizes with the panicle production, fruit formation and new tiller production.

Management

- During day time adult moths rest on the lower surface of the cardamom. They may be collected with insect net and killed.
- The practice of removing the tillers showing 'dead heart' symptoms should be carried with due care.
- Tillers may be removed if the attack is fresh as indicated by extrusion of frass
- The infestation by early stages of larva of this pest in emerging panicle, immature capsule and leaf bud can be controlled effectively with insecticide application.
- Once the late larvae bore and go deep inside the pseudostem, the chemical spray even in its higher dose becomes ineffective.
- Spraying fenthion 0.075% is effective in controlling this pest.

III. Jute semilooper (*Anomis sabulifera*)

Jute is an economically important fibber crop of India which is known for its agriculture based economy. Though India holds first position in raw jute cultivation but never achieved its goal of per capita production to fulfill national and international market demand. Destructive action of *Anomis sabulifera* is one major cause of jute production loss though farmers are using increasing dose of chemical pesticides. Jute semilooper (*Anomis sabulifera* L.) is one of the major threats to the crop. This phytophagous pest feed on both jute pods and unripe seeds that lead to 30.50 - 37.50 % fibre loss. It is reported that in West Bengal semilooper was still a major pest and responsible for 31–34% fibre yield lose every year though chemical pesticide use increased drastically year after year.

Distribution and status: Jute tracts of India, Bangladesh, Myanmar, Sri Lanka and in parts of Africa.

Host range: Specific pest of jute and is the most destructive

Bionomics

Jute semilooper, *A. sabulifera* was a holo-metabolic insect belongs to the order Lepidoptera and family Noctoidae. It was completed its life cycle (Fig) within 28-34 days through four metamorphic stages, which included egg (2-3 days); 5- larval stages (15-17 days); pupa (7-8 days) and adult (5-7 days). The pest passes winter in soil in the pupal stage and the moths appear in May - June, when the crop begins to grow in the field. Healthy gravid mother moth was found to be laid 150-165 eggs on the back of jute leaves. After hatching they were gone through complete metamorphosis with distinct characteristics. The tiny caterpillars, on emerging, feed on the apical leaves and buds undergo 5 moults, in about 17 days. The pupation takes place on the plant or in the soil. In. summer, the pupae emerge in about a week, but those, which diapause, spend the entire winter in that stage. The life-cycle is completed in about one month and several generations are completed in a year.

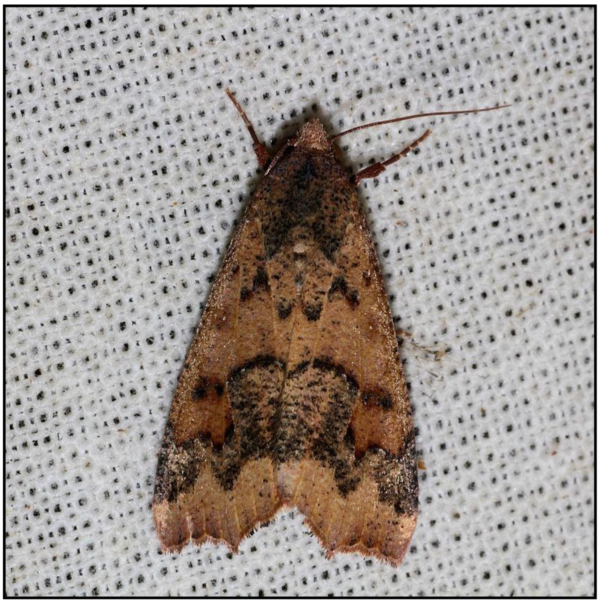


Fig 8: Adult structure of *Anomis sabulifera*

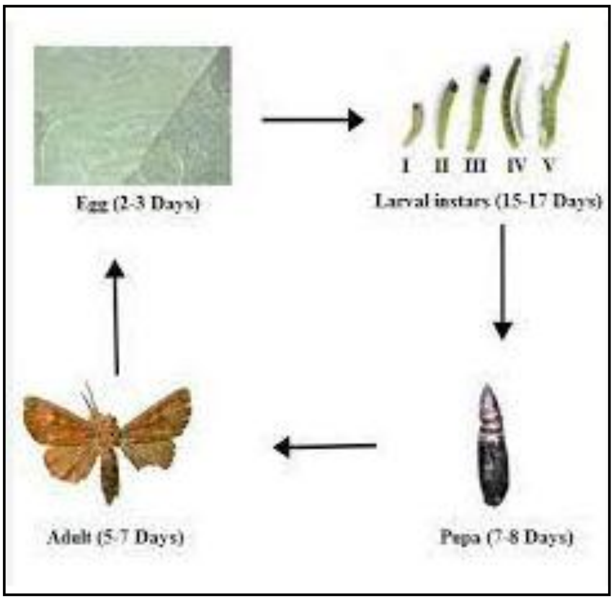


Fig 9: Life cycle of *Anomis sabulifera*

Nature of damage of Jute Semilooper (*Anomis sabulifera*)

- Female insects lay eggs singly on the lower surface of the young leaves.
- After hatching eggs, the caterpillar feeds on apical leaves and buds (1st to 9th leaves).
- As a result, plant growth adversely affected, and yield significantly reduced.
- The attack is severe on half-grown plants which are one meter high. They camouflage but are easily noticed when they crawl by producing a loop in the middle.
- The second generation is the most damaging and sometimes up to 90 per cent of the leaves may be eaten up.
- Generally, the top 7-9 leaves are damaged and plant growth is adversely affected, resulting in a considerable reduction in the yield of fibre.

Management

- Plough the infested fields after harvest to kill the pupae.
- Dislodge the caterpillars into kerosenized water by drawing a rope across the young crop.
- Conserve larval parasitoids *Litomastix gopimobani* (Encyrtidae), *Tricholyga sorbillans* and *Sisyropa Formosa* (Tachinidae).
- Spray endosulfan 35EC in 500 L of water per ha. Repeat the treatments three times at 15- day interval from mid June or at first appearance of the pest.

Probable Questions:

1. Mention the taxonomical position of Fall army worm and *Conoganthes punctiferalis.*
2. What is *Spodoptera frugiperda* commonly known as?
3. Why is Spodoptera frugiperda called fall army worm?
4. Describe the morphological structure of *Spodoptera frugiperda.*
5. How do you identify *Anomis sabulifera* adults?
6. Name the host plants of *Spodoptera frugiperda* and *Anomis sabulifera.*
7. Describe the life cycle of *Spodoptera frugiperda.*
8. Which is the damaging stage of *Spodoptera frugiperda*?
9. How *Spodoptera frugiperda* cause damage to its host plant?
10. What are the natural enemies of *Spodoptera frugiperda*?
11. How do you control *Spodoptera frugiperda* infestation?
12. Elastrate the life cycle of *Conoganthes punctiferalis.*
13. How *Conoganthes punctiferalis* infestation can be controlled?
14. Describe the bionomics of *Anomis sabulifera.*
15. Elastrate the nature of damage of Jute Semilooper.

Suggested Readings:

1. The Insects by Chapman
2. Modern Entomology by D.B. Thembare
3. The Insects by Gullan and Carnston
4. Introduction to Economic Zoology by Sarkar, Kundu and Chaki.
5. A textbook of Economic Zoology by Aminul Islam

UNIT III

Pest management: Mechanical; Chemical

Objective:

In this unit we will discuss about Different mode of Pest management such as Mechanical and Chemical.

Introduction:

Pest control is the regulation or management of a species defined as a pest, a member of the animal kingdom that impact adversely on human activities. The human response depends on the importance of the damage done, and will range from tolerance, through deterrence and management, to attempts to completely eradicate the pest. Pest control measures may be performed as part of an integrated pest management strategy.

In agriculture, pests are kept at bay by cultural, chemical and biological means. Ploughing and cultivation of the soil before sowing reduces the pest burden and there is a modern trend to limit the use of pesticides as far as possible. This can be achieved by monitoring the crop, only applying insecticides when necessary, and by growing varieties and crops which are resistant to pests. Possible, biological means are used, encouraging the natural enemies of the pests and introducing suitable predators or parasites.

In homes and urban environments, the pests are the rodents, birds, insects and other organisms that share the habitat with humans and that feed on and spoil possessions. Control of these pests is attempted through exclusion, repulsion, physical removal or chemical means. Alternatively, various methods of biological control can be used including sterilization programmes.

History:

Pest control is at least as old as agriculture, as there has always been a need to keep crops free from pests. As long ago as 3000 BC in Egypt, cats were used to control pests of grain stores such as rodents. Ferrets were domesticated by 500 AD in Europe for use as mousers. Mongooses were introduced into homes to control rodents and snakes, probably by the ancient Egyptians.

The conventional approach was probably the first to be employed, since it is comparatively easy to destroy weeds by burning them or ploughing them under, and to kill larger competing herbivores. Techniques such as crop rotation, companion planting (also known as intercropping or mixed cropping), and the selective breeding of pest-resistant cultivars have a long history.

Chemical pesticides were first used around 2500 BC, when the Sumerians used sulphur compounds as insecticides. Modern pest control was stimulated by the spread across the United States of the Colorado potato beetle. After much discussion, arsenical compounds were used to control the beetle and the predicted poisoning of the human population did not occur. This led the way to a widespread acceptance of insecticides across the continent. With the industrialization and mechanization of agriculture in the 18th and 19th centuries, and the introduction of the insecticides pyrethrum and derris, chemical pest control became widespread. In the 20th century, the discovery of several synthetic insecticides, such as DDT, and herbicides boosted this development.

A. <u>Mechanical pest control</u>

Mechanical pest control is the management and control of pests using physical means such as fences, barriers or electronic wires. It includes also weeding and change of temperature to control pests. Mechanical control can be accomplished as the follows.

Physical Pest Control Methods

1. **Application of heat-** superheating empty godawn to a temperature of about 10-12 hours will kill the hibernating stored grain insect pests.

2. **Application of refrigeration-** At 5-10°C of all eatables, including dry fruits, will kill the insects.

3. **Manipulation of moisture-** By raising or lowering the moisture content of other materials, unfavorable conditions are created for insect pests.

- By draining away stagnant water, mosquitoes breeding there are killed.
- Reducing the moisture content of grains below 8% would save them the insect pest.
- By soaking the logs in water over an extended period (15 days), insects are drowned.

Mechanical Pest Control Methods

1. Handpicking

The use of human hands to remove harmful insects or other toxic material is often the most common action by this method. Insect can be hand-picked and destroyed of their easily accessible to the pickers large and conspicuous and present in large number of clusters. e.g. Egg mass of rice stem borer, early larval stage of jute hairy caterpillars, adult of sugarcane stem borer etc. can be maintained by hand and destroyed.

2. Use of hand net and bag nets

Some adult insect can be collected and destroyed with hand nets. e.g. Green leaf hopper, Grasshoppers etc. can be controlled with hand nets when they migrate in AprilMay from maize to sugarcane. The bag nets can be used to control the some insects. e.g. Rice hispa from the field partially.

3. Beating and hooking

Various household pest like as housefly, cockroach etc. can be killed by beating with brooms, flappers etc. Again some pests which hide in the holes or crack of host such as Rhinoceros beetle, Jackfruit beetles etc. are killed by hooking with the help of crooked hooks.

4. Shaking and garring

Different insect such as cotton bug, mango shoot borer & defoliator etc. can be killed by shaking the small trees or shrubs. Particularly, every in the morning in cold season when insect are remain in the tree and collecting them tab containing kerosinized water or by hand crashing or leg crushing.

5. Sieving and winnowing

These methods are commonly used against stored grain pest. Some insects, e.g. Red flour beetle are destroyed by collecting them through sieving and some insects. e.g. Rice weevil are destroyed by collecting them winnowing.

6. Mechanical Exclusion

Some of the insects are controlled by creating a barrier for insects in reaching the place where they causes. e.g. Application of a band of sticky material like 'Ostico' or a band of slippery sheets like alkathene around the trunk of a mango tree to prevent the upward movement of the mango mealy bug. Using of screens over the windows, doors and ventilators of house to keep away houseflies, Mosquitoes, bugs etc. Making trench of 30 cm depth around the field and applications on jute hairy caterpillar, Jute Semilooper from infested area to new field; Using red light in the monsoon to keep away most of insects.

7. Use of mechanical traps

Various type of traps have been used for collecting and killing different type of insect

i) Light trap

Light trap can be used to attract and kill the nocturnal insects. e.g. Leaf hopper, Jute hairy caterpillar, moths, stem borer of rice etc. An electric bulb or a lamp is place in the wide flat vessel containing kerosinized in which the moth, beetles get drowned.

ii) Air suction trap

Air suction trap used to against stored grain pest in godown.

iii) Electric trap

Like metal screens are used on which birds or insects are electrocuted.

8. Burning

Locust can be killed by the burning with the help of flame torches. Stored grain pest are also controlled by burning.

9. Crushing and grinding

These devices are used for Sugarcane. Sugarcane shoot borer are controlled by harvesting the sugarcane and then crushing for obtaining sugar.

10. Sound production

These devices are mainly used in scaring these birds which attack fruits and grain crops. This is also used to control some insects like mosquitoes. Male mosquitoes can be attracted to outside of house by producing sound of female mosquito from outside.

11. Rope dragging in field

Rice case worm larva pupates in case prepared by the leaves which remains attached to the plant and can be removed by the dragging rope. Due to this case can fall in the stagnating water and removed easily.

12. Banding the trees

Mealy bugs on mango come on soil for egg laying which can be prevented by putting sticky bands on stem.

13. Bagging the fruits

Fruit sucking moth on citrus or pomegranate suck the juice with the help of stout which can be prevented by bagging fruits.

14. Trenching the field

Pest like army worm, grasshoppers march from one field to other which can be prevented by trenching in field.

15. Tin collars on stem

rat can climb on coconut tree and damage the fruits. When we put the tin collars on stem they cannot climb.

➢ Advantages of Mechanical Methods of pest control

1. Skilled labours are not required.

2. Cost required is very less.

3. There are no any side effects.

- **Disadvantages/Limitations of Mechanical Methods of of pest control**

1. Time and labour requirement is high.

2. This method is applicable only on small scale.

3. This requires repeated application.

B. <u>Chemical Pest control</u>:

Chemical pest control methods have been used for thousands of years by civilizations which had much less knowledge than the current population. Sumerians found out that sulfur gives great results in insect extermination

However, the actual revolution in chemical pesticides happened during the 18th and 19th century when the industrial revolution required much more efficient pest treatments in terms of scale, effectiveness and speed. To present days, chemical pest control methods are among the major types of vermin extermination practices and despite the fact that pesticides often lead to serious health issues, chemical compounds are vastly produced and sold across the whole world.

- **<u>Pesticide</u>**

Pesticides are chemical substances that are meant to kill pests. In general, a pesticide is a chemical or a biological agent such as a virus, bacterium, antimicrobial, or disinfectant that deters, incapacitates, kills, pests.

This use of pesticides is so common that the term pesticide is often treated as synonymous with plant protection product. It is commonly used to eliminate or control a variety of agricultural pests that can damage crops and livestock and reduce farm productivity. The most commonly applied pesticides are insecticides to kill insects, herbicides to kill weeds, rodenticides to kill rodents, and fungicides to control fungi, mould, and mildew.

I. Definition of Pesticides

The Food and Agriculture Organization (FAO) has defined pesticide as:

any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals, causing harm during or otherwise interfering with the production, processing, storage, transport, or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances that may be administered to animals for the control of insects, arachnids, or other pests in or on their bodies.

II. Types of Pesticides

These are grouped according to the types of pests which they kill:

➢ Grouped by types of pests they kill:

1. Insecticides – insects
2. Herbicides – plants
3. Rodenticides – rodents (rats & mice)
4. Bactericides – bacteria
5. Fungicides – fungi
6. Larvicides – larvae

➢ Chemically-related pesticides:

i. Organophosphate:

Most organophosphates are insecticides, they affect the nervous system by disrupting the enzyme that regulates a neurotransmitter.

ii. Carbamate:

Similar to the organophosphorus pesticides, the carbamate pesticides also affect the nervous system by disrupting an enzyme that regulates the neurotransmitter. However, the enzyme effects are usually reversible.

iii. Organochlorine insecticides:

They were commonly used earlier, but now many countries have been removed Organochlorine insecticides from their market due to their health and environmental effects and their persistence (e.g., DDT, chlordane, and toxaphene).

iv. Pyrethroid:

These are a synthetic version of pyrethrin, a naturally occurring pesticide, found in chrysanthemums (Flower). They were developed in such a way as to maximise their stability in the environment.

v. Sulfonylurea herbicides:

The sulfonylureas herbicides have been commercialized for weed control such as pyrithiobac-sodium, cyclosulfamuron, bispyribac-sodium, terbacil, sulfometuron-methyl Sulfosulfuron, rimsulfuron, pyrazosulfuron-ethyl, imazosulfuron, nicosulfuron, oxasulfuron, nicosulfuron, flazasulfuron, primisulfuron-methyl, halosulfuron-methyl, flupyrsulfuron-methyl-sodium, ethoxysulfuron, chlorimuron-ethyl, bensulfuron-methyl, azimsulfuron, and amidosulfuron.

vi. Biopesticides:

The biopesticides are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals.

Here are the major types of chemical pesticides that are used nowadays in agriculture, domestic and commercial properties for pest control of various insects and rodents:

i. Fungicides

Fungicides are chemical compounds or organic organisms with biocidal properties, which help for the destruction of fungi and fungal spores. Fungi may cause severe disruption of any agricultural process. This leads to losses of yield and lowers the final quality of the production. Apart from using fungicides in agriculture, they give very good results when used to cure fungal infections inside animals. The major active ingredient of almost any fungicide is sulphur, which may turn out to be 0.5% of what is contained inside some of the heavier fungicides. Here is the full list of fungicides used in agriculture. Refer to it whenever you need additional information.

➢ Advantages of Fungicides

a. Fungicides control mycotoxin-producing pathogens

b. Great value per cost. An artichoke production company in California earned 27 million pounds ofartichokes for 1 000 pounds of chemical fungicide being invested.

c. Kills fungi and fungal spores with great efficiency

➢ List of Natural Fungicides

Fungi can be controlled effectively without the use of chemicals. It’s much more sustainable and causes no damage to the soil or pollution of any kind. Some plants do great job in the fight with fungi because of their naturally evolved defensive system. Processing plants into sprays, mixtures and compounds of any other kind, turns out to be a great way to make natural fungicide. You can use any of the following extracts for the preparation of natural fungicides: Nimbin, Tea tree oil ,Citronella oil, Jojoba oil, Rosemary oil, Monocerin, Oregano Oil

ii. Insecticides

Substances which are used to kill insects are called insecticides. Insecticides have a wide application in the field of medicine, agriculture, and industry. They have the potential to alter ecosystem components majorly and are toxic to animals as well as humans. Some insecticides become concentrated as they spread in the food chain.

Classification of insecticide

- Based on chemical composition, it is classified as organic and inorganic.
- Based on the mode of entry in the insects, it is classified as contact poisons, fumigants poisons, stomach poisons, and systemic poisons.
- Based on the mode of action, it is classified as physical poisons, nerve poisons, respiratory poisons, protoplasmic poisons, general poisons, and chitin inhibitors.
- Based on toxicity, it is classified into four types:

1. Extremely toxic – Colour: red, symbol: skull and poison, oral LD50: 1-50
2. Moderately toxic – Colour: blue, symbol: danger, oral LD50: 501 – 5000
3. Highly toxic – Colour: yellow, symbol: poison, oral LD50: 51 – 500
4. Less toxic – Colour: green, symbol: caution, oral LD50: >5000

- Based on the stage of specificity, it is classified as ovicides, pupicides, larvicides, and adulticides.

Types of insecticides

There are three different types of insecticides. They are

1. **Systemic** – This type of insecticide is introduced into the soil for it to get absorbed by the plant roots. Once the insecticide enters the roots, it moves to external areas such as leaves, fruits, twigs, and branches. It forms a layer on the plant surface area and acts as a poison to any insect that comes to chew the plant.
2. **Ingested** – Some examples of ingested pesticides are rats and roaches.
3. **Contact** – These types of insecticides act like bullets that aim only at a particular target to kill insects by its application. Usually, household insect spray works like contact insecticides as it must directly hit the insect.

Classification of insecticides based on chemical nature

Based on their chemical nature, insecticides are classified into four groups:

1. **Organic insecticides**
2. **Synthetic insecticides**
3. **Inorganic insecticides**
4. **Miscellaneous compounds**

➢ Disadvantages of insecticides

1. **Non-target organisms –** Insecticides can kill more than intended organisms and are risky to humans. Also, when insecticides mix with water sources through leaching, drift, or run off, they harm aquatic wildlife. When birds drink such contaminated water and eat affected insects, they die. Some examples of insecticides, like DDT, were banned in the US as it affects the reproductive abilities of predatory birds.
2. **Resistance –** Insects when repeatedly exposed to insecticides build up resistance until finally, they have little or no effect at all. The reproduction in insects is so quick that they produce a new generation every three to four weeks. Therefore, the resistance builds up rapidly.

iii. <u>Nematicides</u>

Nematicide is a chemical pesticide which kills nematodes that parasitize on plants. The use of this chemical pesticide is very important for potato crops because of the soil-borne nematodes. Of course, nematicides may be natural such as extracts of neem oil. Non-fumigant nematicides are among the most popular type. They have low volatility and spread easily after sprayed on soil. If water is sprayed on the soil the spreading of the non-fumigant nematicides becomes much faster.

In case the nematicides are naular, you can enhance their effect by manually inserting them deeper in the soil. A rainfall would also help but if the insecticide has been sprayed as a liquid.

Non-fumigant Nematicides

Non-fumigant nematicides have low volatility and diffuse through the soil (generally for short distances only) dissolved in the soil solution. Their movement may be enhanced by water movement through irrigation or rainfall. If in granular formulations, their distribution may be enhanced by physical incorporation into the soil.

➢ Disadvantage of Nematicides

a. Groundwater contamination with toxins

b. Exposure to chemicals

c. People who use machinery for insecticide application are at higher risk.

d. Delayed harvest

e. Specific minimum time for residual effect to fade away is required which may postpone harvest.

f. Pesticide poisoning

g. Higher levels of mortality occur when certain regulations for usage are not followed.

iv. Rodenticides

Rodenticides are chemical pesticides, designed specifically for the extermination of rodents such as rats and mice. Most rodenticides are lethal and do not serve only as repellents. They are produced and applied in the form of food which the rodents consume. It may take several hours to a few days for a rodent to be killed after consuming a rodenticide.

However, rodents often sense the threat and observe the rodenticide for a long time before consuming it. This is known as poison shyness and to reduce this, scientists now develop rodenticides with a very strong residual effect. Instead of killing the rodent instantly, it causes dehydration and haemorrhage which cannot be stopped. This helps for avoiding problems related to rodents dying inside tiny crevices.

☐ Advantages of Chemical Pest Control method:

a. Effectiveness

Chemicals exterminate any pest that hasn't adapted to the deadly substance inside the agent. They eradicate fast and with an efficiency of up to 100%. Most are very easy to apply and can get in the way of pests that hide in small crevices and other hidings.

b. Quickness

Some chemicals for pest control kill slowly because of the active ingredient. However, most pesticides are designed to exterminate the vermin in less than 3-4 days, which is much faster compared to organic methods of pest control such as importation or augmentation.

c. Precise targeting (localized)

Contrary to biological pest control methods, the chemical substances may target a specific area with high precision. On the other hand, if you release pest-destroying animals, there is no control over theirbehaviour – they may spread wherever they want.

d. Easy application

This one helps the customers a lot in their efforts towards DIY pest control with ready-to-use products. Most pesticides sold on the market are packed inside bottles, designed for easy use and application. They are readily available and spraying them on your crops takes few minutes and a little more time before that to read the instructions, which is something we highly recommend before using pesticides of any type.

e. Improving productivity

Pesticides become more and more effective in time but sometimes at the cost of being more toxic and unsustainable. Efforts of scientists are made towards researching pesticides that cause lower pollution and side effects on human health. However, it's difficult to achieve that because animal species evolve against the chemicals and more poison is required to exterminate pests that are resistant to the old forms of pesticides.

f. Sports facilities maintenance

Sports facilities such as pitches and football terrains are endangered by pests too. If the turf is not maintained properly, it will be destroyed and the field will become unusable. Pesticides are used even there for the exterminate pests such as white grub worms, chinch bugs, bluegrass weevils, ants and more.

☐ Disadvantages of <u>Chemical Pest Control</u> method:

a. Promote evolution

The use of chemical pesticides stimulates the pest to develop resistance to the chemicals used in the pesticides. The resistance is based on alterations in the genetics of the vermin and every future generation becomes increasingly pesticide-proofed. This works very well among rodents which produce several litters per year.

b. Resurgence (non-precise targeting)

Resurgence happens when the use of pesticides affects the environment and disrupts the organic pest control. The most tremendous side effects of all are when significant animal species such as bees get killed by collateral damage after spraying with chemical pesticides.

Another side effect of resurgence is when pest-destroying animals such as parasitoid wasps are killed and they pray, mostly other pest insects, no longer have a natural enemy and start to multiply so quickly that completely overwhelm entire agriculture.

c. Persistent Organic Pollutants

POP, known as persistent organic pollutants, are extremely dangerous to the non-target organism but also affect the health of people by causing cancer, infertility or problems to the endocrine system.

<u>Impact of Chemical Pesticides on the Environment:</u>

a. Surface water contamination: Pesticides can reach surface water through runoff from treated plants and soil. Contamination of water by pesticides is widespread. Pesticides were found in all samples from major rivers with mixed agricultural and urban land.

b. Ground water contamination: Groundwater pollution due to pesticides is a worldwide problem. At least 143 different pesticides and 21 transformation products have been found in ground water, including pesticides from every major chemical class. Over the past two decades, detections have been found in the ground water of more than 43 states. During one survey in India, 58% of drinking water samples drawn from various hand pumps and wells around Bhopal were contaminated with Organo Chlorine pesticides above the EPA standards. Once ground water is polluted with toxic chemicals, it may take many years for the contamination to dissipate or be cleaned up. Cleanup may also be very costly and complex, if not impossible

c. Soil contamination: A large number of transformation products (TPs) from a wide range of pesticides have been documented. TPs have been monitored in soil. The most researched pesticide TPs in soil are undoubtedly those from herbicides. Several metabolic pathways have been suggested, involving transformation through hydrolysis, methylation, and ring cleavage that produce several toxic phenolic compounds. Presence of these compounds alters the soil ph also.

Heavy treatment of soil with pesticides can cause populations of beneficial soil microorganisms to decline.

d. Air contamination: Pesticide sprays can directly hit non-target vegetation, or can drift or volatilize from the treated area and contaminate air, soil, and non-target plants. Some pesticide drift occurs during every application, even from ground equipment

e. Effects on plants: A non-target plant becomes affected with the application of herbicides. pesticide exposure can cause sublethal effects on plants. Phenoxy herbicides, including 2,4-D, can injure nearby trees and shrubs if they drift or volatilise onto leaves. Exposure to the herbicide glyphosate can severely reduce seed quality. It can also increase the susceptibility of certain plants to disease

f. Effects on animals: Pesticides are found as common contaminants in soil, air, water and on non-target organisms in our urban landscapes. Once there, they can harm plants and animals ranging from beneficial soil microorganisms and insects, non-target plants, fish, birds, and other wildlife. Chlorpyrifos, a common contaminant of urban streams is highly toxic to fish. It kills in waterways near treated fields or buildings. Herbicides can also be toxic to fish. Several cases of pesticide poisoning of dolphins have been reported worldwide. Because of their high trophic level in the food chain and relatively low activities of drug-metabolising enzymes, aquatic mammals such as dolphins accumulate increased concentrations of persistent organic pollutants.

Herbicides may hurt insects or spiders also indirectly when they destroy the foliage that these animals need for food and shelter.

Non-target birds may also be killed if they ingest poisoned grains set out as bait for pigeons and rodents.

Probable questions:

1. What do you mean by mechanical pest control? Elaborate its application methods?
2. Describe different types of mechanical traps used in mechanical pest control method.
3. Describe the advantage and disadvantages of mechanical pest control.
4. Describe the limitation of mechanical pest control.
5. What do you mean by Chemical Pest control method?
6. Define pesticide. State its role in chemical pest control.
7. Classify pesticides with example based on different types of pests they kill.
8. Classify pesticides with example on the basis of its chemical nature.
9. What do you mean by Pyrethroid?
10. What is fungicide? Name some natural fungicide. Describe the advantage of fungicide application.
11. What do you mean by systemic insecticide? Give example.
12. State the disadvantages of insecticides application.
13. What is rodenticide? Give example.
14. Describe the advantages of chemical pest control method.
15. Elucidate the impact of chemical pesticides on the environment.

Suggested Readings:

1. The Insects by Chapman
2. Modern Entomology by D.B. Thembare
3. Economic Zoology by Shukla and Upadhyay
4. The Insects by Gullan and Carnston
5. Introduction to Economic Zoology by Sarkar, Kundu and Chaki.

UNIT IV

Pest management: Biological; Integrated

Objective:

In this unit we will discuss about Different mode of Pest management such as Biological and Integrated.

C. Biological Control of Pests:

Biological control may be defined as the utilization of a pest's natural enemies in order to control that pest. It is the control of pests and parasites by the use of other organisms, e.g., of mosquitoes by fishes which feed on their larvae. In other words, it is a practice in which an organism is used against another organism.

Under this practice, there are four types of pest control:

(i) Classical biological control or **importation**, in which a natural enemy from another geographical area, often the area in which the pest originated from, is introduced to contain the pest below the economic injury level, EIL, the definition of EIL is the pest density at which the difference between ne curve showing value of the crop and the curve showing cost of achieving this pest density is neatest;

(ii) **Inoculation**, in which the periodic release of a control agent is required so that it is available throughout the year. Inoculation is widely practiced in the control of arthropod pests in glasshouses, where crops are removed, along with their pests and their natural enemies at the end of the growing season;

(iii) **Augmentation,** which involves the release of an indigenous natural enemy in order to supplement an existing population, and is therefore carried out repeatedly usually to coincide with a period of rapid growth of pest population; and

(iv) **Inundation,** which s the release of large numbers of natural enemy, with the aim of killing those pests present at the time. These are usually termed biological pesticides. However, insects have been main agents of biological control against both insect pests and weeds.

General Theory of Biological Control:

The classical theory of biological control based on the Nicholson-Bailey model is an equilibrium theory (Huffaker and Messenger, 1976). According to this theory, a successful biological control IS produced by the predator imposing low, stable host equilibrium (Fig. 3.9).

But a successful bio-control agent should be host-specific, synchronous with the pest, should have high intrinsic rate of increase (r), should be able to survive with few prey available, and should have high searching ability. All these properties are shown by insect parasitoids than predators. Successful bio-control agents cause density-dependent losses in the hostpopulation.

Spatial density dependence occurs when parasitoids or predators cause a higher fraction of losses in dense host patches than in sparse host patches (Hossell, 1977). If predators can aggregate in patches of high host density, then, according to this theory, biological control of the pest is much more likely. The theory has been challenged recently by Murdoch et al. (1985). They have based their view on a non-equilibrium model of predator-prey interaction. The model assumes that a stable equilibrium of predator and prey is not necessary for satisfactory biological control. Pest populations may fluctuate wildly without pest densities exceeding the economic threshold. According to Krebs (1994), the non-equilibrium model is a meta-population model and, as such, emphasizes that population in different patches may fluctuate independently.

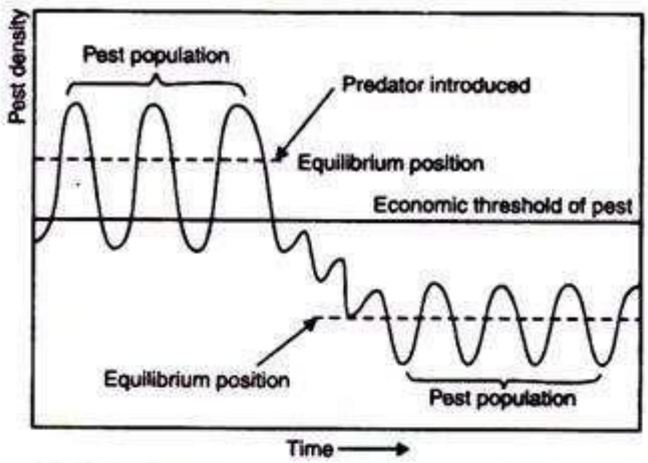


Fig. 3.9. Classic type of biological control in which the average abundance of an insect pest is reduced after the introduction of a predator. The economic threshold is determined by humans' activities, and its position is not changed by biological control programmes. (After van den Bosch *et al.* 1982)

Biological Control by Predators and Parasitoids:

Although predators are considered poor candidates for biological control, they have been used in a number of cases. For example, a small predaceous ladybird beetle, *Rodolia cardinalis*, commonly called vedalia, has been used to control the cottony-cushion scale insect (Iceryapurchasi), a pest of citrus trees. Adult Parasitoids (Hymenoptera) lay their eggs in or near other insects. The larval parasitoid then develops inside its host and kills it before or during the pupal stage.

Biological Control by Parasites:

Some calcid wasps control a number of major pests. The oriental fruit fly, Dacus dorsalis, a pest of ripe fruits in Hawaii has been controlled by three species of parasitic wasps of the genus Opius (*O. vandenboschi, O. longicaudatus and O oophilus*). This example also illustrates that several parasites of the same pest can be released without having any adverse effect on the overall control. Although the three control agents competed for the same host, the one with superior qualities displaced the others and became dominant.

In this case *O. vadenboschi* derived the advantage from attacking first instar larvae and thereby inhibiting the development of the eggs and larvae of *O. longicaudatus*, which favoured older host larvae for oviposition. Likewise, *O. oophilus*, which oviposits in the eggs of the host, are already present as larvae by the time hosts are suitable for attack by *O. vadenboschi.*

The geometrid moth Operopheterabrumata or winter moth, a pest (defoliator) of hardwood forest and ornamental trees in Canada and Europe, has been controlled by a tachinid fly, *Cyzenis albicans*, and a wasp *Agrypon flaveolatum*. However, in this case there was no displacement. Instead, the two species that are compatible and complimentary to each other were able to bring about control. *C. albicans* was very effective at high host densities, whereas the superior searching ability of *A. flaveolatum* made it effective at low host densities.

(a) Bacteria:

The use of spore-forming bacteria as a means of controlling the larvae of the Japanese beetle (*Popillia japonica*), a serious pest of fruits and vegetables, provided the first encouragement for the application of bacteria in insect control. *Bacillus popilliae* and *Bacillus lentimorbus* that cause types A and B milky disease of Japanese beetle can both be mass produced and are sold as a spore dust for injection into the soil. Infected larvae that die in the soil become 1 source of contamination for other larvae feeding in the vicinity. Larval population can be substantially reduced in this way and the Bacillus spores persist in the soil to infect larvae from generation to generation.

Another spore- forming bacteria Bacillus thuringiensis is a facultative pathogen that infects a variety of insects, including the larvae of lepidopterans, flies, and beetles. The bacteria can be cultured on artificial media and is therefore quite economical to produce. Commercial preparations of *Bacillus thuringiensis* (Biotsol, Dipel, Thuricide) containing both spores and crystals are used is a biological insecticide on a variety of crops. The rather specific nature of *Bacillus thuringiensis* to kill a few groups of foliage feeders and not to harm beneficial species is of great value in management programmes.

(b) Fungi:

Most entomogenous fungi are internal pathogens. They belong to all the four major taxonomic groups of true fungi, but only a few are frequently associated with insect disease outbreaks. The most commonly used in insect control are Beauvariabassiane (white muscardine disease) and Metarrhiziumanisopliae (green muscardine disease), both of which are fungi imperfect. The infective unit of an entomogenous fungi is usually a spore which germinates on the surface of the host's integument. Once the host tissue is invaded, the fungus can complete its life cycle, but the survival and germination of spores is critical to the development of an epidemic. Facultative fungi such as Beauvaria and Metarrhizium can be cultured on artificial media, thereby facilitating the production of spore preparations which may be used in biological control. As with most biological control agents, fungi can be used for either persistent or short-term control. A fungus can be introduced into an area where it becomes established and kills the host year after year. Alternatively, fungal spore preparations can be used as microbial insecticide similar 10 the way *Bacillus thuringiensis* is used. However, few attempts have been made to colonize entomogenous fungi. Most projects have involved the redistribution of indigenous fungi or those associated with introduced pests, rather than the importation of foreign species. The best example of attempts to establish new fungal pathogens in disease free areas involves the introduction of Coelomomyces against mosquito larvae, but so far the success has been limited. The successful use of repeated application of fungal spores as microbial insecticides has been reported for achieving short-term reductions of pest populations. The major limiting factor in initiation of fungal disease in insect populations is the effect of the microclimate on spore survival and germination.

The optimal temperature range for the growth of entomogenous fungi is fairly narrow, and relatively high humidity is needed by most fungi to germinate and successfully penetrate their host before they can produce the new spores required to spread the disease. Sunlight also kills the spores. Consequently, the application of a spore preparation must coincide with both the presence of susceptible hosts and suitable environmental conditions. Best success can usually be obtained by applying the spores in the absence of sunlight such as on a warm evening after either rain or irrigation which provides the needed humidity.

(c) Viruses:

The insect pathogenic viruses are called inclusion viruses, as opposed to non-inclusion viruses in which the virus particles or viruses are free within the cells of the host. The virus particles first multiply in the nuclei, but later continue to replicate in the cytoplasm. The disease eventually kills the insect, leaving it hanging as a fragile sac of virus like the one which results from nuclear polyhedroses infection. A few non-inclusion viruses also attack insects. But with the exception of Tipula Iridescent Virus (TIV) and Mosquito Iridescent Virus (MIV) that might prove useful in mosquito control, most attention has been given to the inclusion viruses. The very fact that the virus particles enclosed in a protein matrix maintain their infectivity for many years means that the inclusion viruses can be stored as concentrated preparations for later application with conventional pesticide spray equipment.

It has been shown that a nuclear polyhedroses virus is highly effective against a variety of forest sawflies and, as it persists in the environment, it provides continuous regulation of the pest in some areas. Several nuclear polyhedroses virus are being mass produced for possible use against a variety of pests, including cotton bollworm, tobacco budworm, com earworm, cabbage looper, forest tent caterpillar, and alfalfa butterfly. However, one of the problems with viruses is that there are periods when they have little effect on the pest populations. A virus may remain latent in a pest population for several generations and then develop epizootics when the pest population comes under stress. Generally, short-term control can be achieved by frequent applications of virus preparations so that there is an active innoculum in the pest environment for a long period.

Genetic Control:

Genetic control is a type of biological control that uses two strategies to reduce pest problems. First, crop plants can be manipulated to increase their resistance to pests. Second, we can attempt to alter the genome of the pest species so that they become sterile or less harmful. Resistant varieties of many crop plants have been developed by selective breeding (Maxwell and Jennings, 1980). However, resistant plants do not necessarily have chemical defences. Strains of cotton plant produced with low gossypol (a chemical that occurs in green parts and seeds of cotton plant and is toxic to chickens and pigs) content are quite low in resistance to insect pests. Resistant crop plants have also been developed by genetic engineering. Genes that produce resistance in one species can be transferred into a crop plant to make the crop genetically resistant to specific pests. Bacteria may also be used as vehicles to carry bio-pesticide genes. For example, in 1987 the first success was reported of inserting a gene (the toxin gene of *Bacillus thurengiensis*) into tobacco plants, conferring resistance against Lepidoptera. *Bacillus thurengiensis* (Bt) is the main focus at present for developing insect resistant crops (Lambert and Peferoen 1992).

This bacterium normally lives in the soil and carries a gene for a toxic protein that kills the larvae of moths and butterflies. By splicing this gene into bacteria that normally live on crop plants, genetic engineers have produced insect- resistant crops. Insect pests would inject the bacteria while feeding on the plant and thereby is poisoned. Alternatively, the Bt genes that produce the toxins can be transferred directly into the plant's genome, so that the plant would protect itself As of 1992 tobacco, potato, cotton and tomato plants have been genetically engineered with Bt genes (Lambert and Peferoen, 1992). The development and use of such transgenic plants has immense potential. However, one major problem is that pest insects will become resistant to the bio-pesticide, just as they become resistant to chemical pesticides (Pimentel 1991).

The simplest genetic manipulation that can be carried out on a pest species is sterilization. A large number of pests are sterilized by radiation or by chemicals and released into the wild where they can mate with normal individuals. This technique leads to a decrease in birth rate of the pest and control can be achieved. The most notable success of this technique is the near extinction of the screw-worm fly, *Cochliomyia hominivorax*, which lays its eggs on fresh wounds of livestock and wild animals. Another example of successful use of sterile-insect method was the suppression of mosquito *Culex pipiens quinque fasciatus* on a small island off Florida (Patterson, et.al. 1970). However, the sterile insect method cannot be used for all pest populations because it requires the rearing and sterilizing of a large number of individuals and isolation of target area so that natural males from outside the area may not be able to reach there to undermine the programme.

Advantages of Biological Control:

1. Biological control is a very specific strategy. The vast majority of the time, whatever predator is introduced will only control the population of the pest they are meant to target, making it a green alternative to chemical or mechanical control methods. For example, whereas weed-killing chemicals can also destroy fruit-bearing plants, biological control allows the fruit to be left uninterrupted while the weeds are destroyed.

2. Natural enemies introduced to the environment are capable of sustaining themselves, often by reducing whatever pest population they are supposed to manage. This means that after the initial introduction, very little effort is required to keep the system running fluidly. It also means that biological control can be kept in place for a much longer time than other methods of pest control.

3. Biological control can be cost-effective in the long run. Although it may cost a bit to introduce a new species to an environment, it's a tactic that only needs to be applied once due to its self-perpetuating nature.

4. Most important of all, it's effective. Whatever pest population you want controlled will no doubt be controlled. Because the predator introduced will be naturally inclined to target the pests, very often you'll see the pest population dwindle.

Disadvantages of Biological Control:

1. Biological control can be fickle. Ultimately, you can't control whatever natural enemy you set loose in an ecosystem. While it's **supposed** to manage one pest, there is always the possibility that your predator will switch to a different target - they might decide eating your crops instead of the insects infesting them is a better plan! Not only that, but introducing a new species to an environment runs the risk of disrupting the natural food chain.

2. It's a slow process. It takes a lot of time and patience for the biological agents to work their magic on a pest population, whereas other methods like pesticides work provide immediate results. The upside to this is the long-term effect biological control provides.

3. If you're looking to completely wipe out a pest, biological control is not the right choice. Predators can only survive if there is something to eat, so destroying their food population would risk their own safety. Therefore, they can only **reduce** the number of harmful pests.

4. While it is cheap in the long run, the process of actually setting up a biological control system is a costly endeavor. A lot of planning and money goes into developing a successful system.

D. Integrated Pest Management (IPM)

Definition of IPM:

Integrated Pest Management (IPM) is a process consisting of the balanced use of cultural, biological, and chemical procedures that are environmentally compatible, economically feasible, and socially acceptable to reduce pest populations to tolerable levels.

Integrated means to combine. It is a combination of many strategies that are used to avoid or solve a pest problem. These strategies come from different disciplines, such as disease information from plant pathologists, weed information from agronomists, and insect information from entomologists.

Pests are unwanted organisms that are a nuisance to man or domestic animals, and can cause injury to humans, animals, plants, structures, and possessions. Management is the process of making decisions in a systematic way to keep pests from reaching intolerable levels. Small populations of pests can often be tolerated; total eradication is often not necessary.

Why Practice IPM?

It is a pertinent question to ask, why should one consider IPM when chemical pesticides so often succeed at controlling pests? There are some reasons for having a broader approach to pest management than just the use of chemicals.

These are given below:

(a) To Keep a Balanced Ecosystem:

Every ecosystem is made up of living things and their non-living environment. The living and nonliving constituents of the ecosystem maintain a highly tuned balance in nature. The actions of one creature in the ecosystem usually affect other organisms of same or different species.

The introduction of chemicals into the ecosystem can change this balance, destroying certain species and allowing other species (sometimes pests themselves) to dominate. Beneficial insects such as the ladybird beetle and lacewing larvae, both of which consume pests, can be killed by pesticides, leaving few natural mechanisms of pest control.

(b) Pesticides can be Ineffective if not used in IPM Method:

Chemical pesticides are not always effective. Pests can become resistant to pesticides. In fact, some 600 cases of pests, developing pesticide resistance varieties have been documented to date, including common lamb's-quarter, houseflies, the Colorado potato beetle, the Indian meal moth, Norway rats, and the greenhouse whitefly.

Furthermore, pests may survive in some situations where the chemical does not reach it and is washed off. It may be applied at an improper rate, or is applied at an improper life stage of the pest.

(c) IPM is not difficult:

If one have figured out the problem (the pest), determined the extent of the damage and decided on the action to take, he has already done most of the important steps in IPM. These steps are the ones used in 1PM. Therefore, it is very easy to practise.

(d) IPM Saves Money:

IPM can save money through avoiding crop loss (due to pests), and avoiding unnecessary pesticide expenses. For example, onion growers who followed IPM recommendations in 1987 saved more than Rs 1000.00 per acre in insecticide costs.

Golf course superintendents who replace fungicides with organic fertilizers or composts can save up to Rs 60000.00 every time. Applicators are able to save on sprays because the calendar is not the basis for spraying; the need is the basis.

(e) To Promote a Healthy Environment:

Nowadays a severe problem to mankind is arising with the persistent presence of different chemicals in the environment along with their effect on living creatures. Reports of several cases of contaminated groundwater appear each year.

Disposal of containers and unused pesticides pose challenges for applicators. Even though long-term documentation on the effects of all pesticides is still unavailable, it is generally agreed that fewer pesticides means less risk to surface water and groundwater, and less hazard to wildlife and humans.

(f) To Maintain a Good Public Image:

Recent public outcry about the presence of pesticide residues on produce and the use of growth regulators has heightened pesticide applicator awareness of the level of public concern about chemicals. Consumers are pressurizing food stores, which in turn are pressurizing producers for products that has been grown with as few pesticides as possible.

Growing food under 1PM can help allay public concerns. Structural pest control professionals can suggest improvements in housekeeping or structural modifications as substitutes for chemical control.

The Basic Steps of IPM:

IPM is based on taking preventive measures, monitoring the crop, assessing the pest damage, and choosing appropriate actions. Many different tactics are used in IPM, including cultural practices, biological control agents, chemical pesticides, pest-resistant varieties, and physical barriers.

All of the components of an IPM approach can be grouped into four major steps:

1. The first step is taking preventative measures to prevent pest build-up.

2. The second is monitoring.

3. The third step is assessing the pest situation.

4. The fourth is determining the best action to take.

These steps are thoroughly discussed below:

1. First Step of IPM: Preventative Measures:

Many IPM practices are used before a pest problem develops to prevent or stall the build-up of pests.

Cultural controls are those that disrupt the environment of the pest. Ploughing, crop rotation, removal of infected plant material, sanitation of greenhouse equipment and effective manure management, are all cultural practices that are employed to deprive pests of a comfortable habitat.

The management of urban and industrial pests has improved when sanitation programs have been improved, pest harborages eliminated, garbage pickup frequency increased.

Structural modifications such as by preventing support timbers from soil contact, damages from several different wood destroying pests can be avoided. Wood absorbs moisture and is more susceptible to attack by carpenter ants and termites when in direct contact with the soil.

Construction Site Sanitation:

Removing of tree stumps and lumber scraps from construction sites, which are prime food sources for subterranean termites, can prevent problems in the future. Biological controls by using natural enemies (biological control agents) to keep pests in check can be put into place before pest problems increase.

Examples of biological control agents are beneficial mites that feed on other mite pests in orchards, the milky spore disease that kills harmful soil grubs and Encarsia formosa, a wasp that parasitizes the greenhouse whitefly. Many biological control agents are commercially available.

Physical barriers such as netting over small fruits and screening in greenhouses can prevent crop loss. Physical barriers are important in termite, housefly, and rodent control.

Use of pheromones (natural insect scents) has become widely used in pest management. Sometimes a manufactured "copy" of the pheromone that a female insect emits to attract mates can be used to confuse males and prevent mating. This technique is used in curbing damage from the grape berry moth.

Pest-resistant varieties of cultivable plants are those, which are less susceptible than other varieties to certain insects and diseases. Use of resistant varieties often means that growers do not need to apply as many pesticides as is with susceptible varieties.

Potato growers control the golden nematode by planting resistant cultivars. Apple growers can save up to eight fungicide applications a year by growing Liberty and Freedom cultivars, which resist diseases. Farmers growing alfalfa and wheat keep several pests at bay by planting resistant varieties.

Once a pest manager has taken precautions to prevent pest infestations, it is important to watch regularly for the appearance of insects, weeds, diseases, and other pests.

2. Second Step of IPM: Monitoring (Scouting):

Monitoring Pests Involves:

(a) Regular checking of the infested area.

(b) Early detection of pests.

(c) Proper identification of pests.

(d) Identification of the effects of biological control agents.

Regular checking of a warehouse, bakery, restaurant, field, greenhouse, golf course, or other areas and early detection of pests can function together like an early warning system for pests, helping to avoid or prevent a pest problem.

Proper identification of pests is an extremely important prerequisite for handling problems effectively. For example, the brown banded cockroach and German cockroach can be easily confused with each other. Identification is important because certain management practices may control only one species and not the other.

Correct identification enables to manage the real source of the problem and avoid merely treating the symptoms (or controlling non-pests). Some pests cause similar evidence. Unless the pest is identified, the control programme may have the wrong pest as its target.

Identification enables to cure the pest problem and avoid injury to non-target organisms, particularly if:

(a) Use a pesticide that is specific to the pest.

(b) Control the pest effectively during the most susceptible stage of its life cycle.

(c) Consider the use of a non-chemical control.

Identifying the effects of biological control means knowing which creatures are helpful and determining if pests are affected by the beneficial organisms. Sometimes pests are kept in check naturally, and at other times the pest populations increase sharply.

3. Third Step of IPM: Assessment:

Assessment is the process of determining the potential for pest populations to reach an economic threshold or an intolerable level. There are important differences between the assessment of crop and urban pests.

Forecasting can help to determine weather conditions will be favourable for the development of diseases and insect pests. For example, by “plugging in” values (such as the number of rainy days and the temperatures for those days), growers can predict outbreaks and spray only when conditions are favourable for diseases.

Growers who have kept good records of pests in previous years can use these records to help determine if problems such as weeds, insects, and diseases will re-occur. They might be able, for example, to apply the most effective herbicides at the proper time for early control of a problem.

Thresholds, or more specifically economic thresholds, are levels that mark the highest point a pest population can reach without risk of economic loss. Populations above these thresholds can reach the economic injury level, where they cause enough damage for the grower to lose money. At the economic injury level, the cost of control is equal to the loss of yield or quality that would result otherwise (see Fig. 1.21).

Thresholds for many crops and pests have been scientifically determined. The advantage of thresholds is that if a pest has not reached threshold, there is no risk of economic loss. Therefore, there is no need to apply any control measure.

Once the pest density (number of pests per unit area) has reached threshold, action should be taken. The costs of control must be less than or at least equal to the estimated losses that the pests would cause if left uncontrolled.

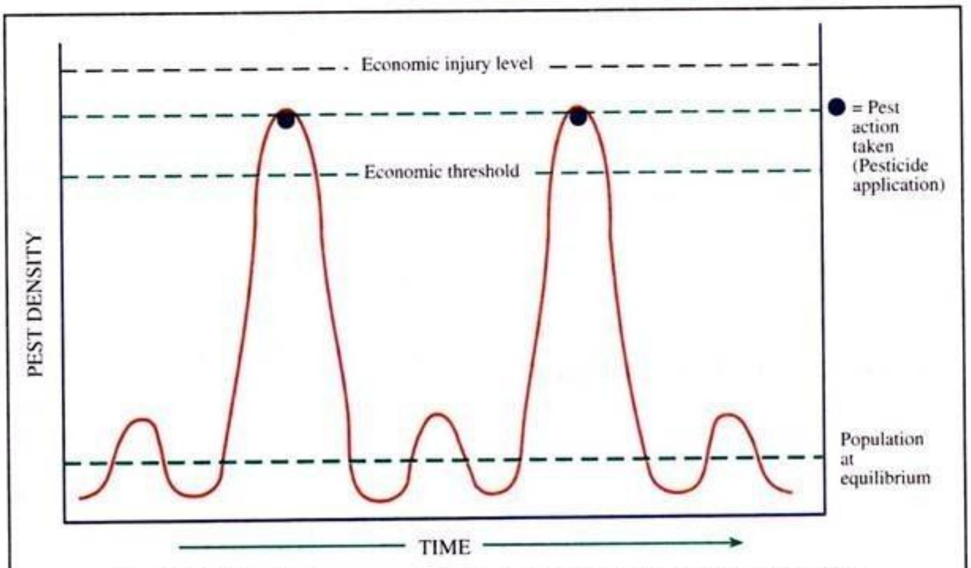


Fig. 1.21. Relationship between economic threshold, pest population density, and pesticide application point is shown

Zero Thresholds:

Urban pest thresholds are often related to aesthetics rather than economic considerations. Where health concerns or individual sensitivities exist, the tolerable level of the pest may be zero. A zero threshold forces action, even if only one pest has been detected. Zero thresholds exist in hospitals, food production, warehousing, and retail facilities.

4. Fourth Step of IPM: Action (Control Measures):

Once a pest has reached the economic threshold, or intolerable level, action should be taken. In some situations, cultural controls can destroy pests. One example is early harvesting to avoid pest problems, which prevents crop loss and can sometimes be more economical than a pesticide application.

Chemical pesticides are used as a control measure when no other strategies will bring the pest population under the threshold. In fact, the success of waiting until a pest reaches threshold usually hinges on the availability of a pesticide that will bring the pest populations down quickly.

In summary, an IPM approach means that pest managers use multiple tactics to prevent pest buildups, monitor pest populations, assess the damage, and make informed management decisions, keeping in mind that pesticides should be used judiciously.

Philosophy of Integrated Pest Management (IPM):

Integrated Pest Management or 1PM provides a systematic approach to pest control. It begins with using the best cultivation practices. Following the correct selection and culture of plants, reduces the potential for pests and diseases.

When problems arise, the essential step in an IPM program is determining when a pest is causing enough damage to warrant control. It also helps the cultivator to determine which of the many possible control measures is most effective and appropriate in a particular situation. IPM can be applied to all floral and faunal pest groups.

Correct Cultural Practices:

Cultural practices should be designed such that the cultivator has ways and means of implementing correct practices as per changing environmental factors that affect the plants and their pest populations. Cultural practices include irrigation, crop rotation, garden sanitation, soil aeration, mulching, tilling and use of disease- and pest-resistant plants. It is essential that the cultivators should know critically the cultural or growing requirements of each plant.

Providing the correct growing conditions result in a vigorous plant that is less likely to be attacked by pests and diseases. Vigorous plants also can tolerate tissue damages.

The question of when an organism becomes a pest is central to IPM. Deciding how much damage is acceptable with a particular plant or crop is called “establishing a threshold”.

Establishment of Threshold:

Several factors influence how each cultivator will arrive at a pest threshold.

These factors include the following:

1. Amount of damage that can be tolerated.

2. Pest population size required to cause significant damage.

3. The plants' stage of development.

4. The vigour of the threatened plant(s).

5. The life cycle and habits of the pest.

The amount of damage that can be tolerated varies with the crop and personal preferences. A few holes on a collard leaf do not require control. However, if most of the leaf has been eaten, the crop is destroyed.

Less than 12 white grubs in a square foot of turf grass can be tolerated as long as the lawn is growing vigorously. However, if the density of grubs rises above 12 per square foot, damage will be significant.

Colorado potato beetles devastate a potato crop early in the season. However, in the latter part of the season, they feed on the foliage and practically no damage is done to the crop.

Peach tree borers are extremely difficult to control once they bore into the trunk of the tree. Knowing that the adults lay eggs in mid-July to mid-August and that the young larvae are susceptible during this period, the cultivators are advised to effectively apply control measures.

Establishing thresholds in the field involves observing the plant and its total environment.

There is also the question: Does the cure process cause more damage than the pest? There is a risk involved in using the more toxic pesticides. This risk must be weighed against the potential benefit.

Inspection and Monitoring:

One must monitor the field to determine when action is necessary. Thorough inspection of the plant includes – the underside part of leaves, buds, new growth and even the roots in extreme cases. Regular inspection allows the cultivator to identify a problem before major damage occurs to the plant.

Controls will be more effective if the problem is caught early. Infrequent inspection results in extensive damage. Once extensive damage occurs, it is often too late to do anything.

Inspection of the plant's entire environment for clues to the problem is a good practice for a good cultivator. Too much or too little moisture, wind, humidity and light may cause stress that results in susceptibility to damage from pests and diseases. Observing and keeping records of weather conditions provide clues to growth patterns and problems.

Certain insect pests can be monitored by using traps. Coloured, sticky traps, pheromone traps, pitfall traps and light traps are used with some pests. White- flies and aphids are attracted to bright yellow, sticky cards and are trapped on the sticky surface.

Identifying the Cause of the Problem:

The problem may be caused by insects or related pests, diseases or cultural practices. Often, the problem is caused by a combination of these factors. Identification of the pest or disease and the conditions that allow organism to become a problem is of prime importance. Reference materials are guide to common problems for a particular plant.

They list the insects and diseases that attack each plant. The ORTHO PROBLEM SOLVER is an excellent resource for identification. A questioning attitude and close inspection are required to make an accurate diagnosis.

A magnifying or hand lens is helpful. Close examination of the specimen for feeding or disease patterns is essential. If insects are involved, collection of the pest is essential. Identification of insects and diseases is available through local Extension offices and the Plant and Pest Identification Organizations.

Application of Control Measures:

To apply a control measure, one must understand the pest organism, its life cycle and the type of damage it causes. All control options should be considered. The most effective and appropriate option or combination of options should be selected. Control measures should be taken as fast as possible and at the right time.

Insects are more vulnerable at certain stages of their life cycle. Eggs may be controlled with oil sprays. Larval stages are particularly vulnerable. It is critical to control insects before they reproduce and increase their population. When an insect is protected by the pupal case, control is nearly impossible.

Re-application of control measure may be necessary for many pests to kill the young as they emerge from eggs. It is important to know, how long the pesticide remains effective on the plant. This is also important in food crops. Cultivator must observe the prescribed time lapse between the last application and harvest.

Diseases are more difficult to control. Most of the fungicides prevent infection or at best stops an infection from spreading. Netting is not effective if there are unprotected areas. Pesticides must be applied to both the top and underside of leaves.

Surfactants or spreader/stickers help the pesticide adhere to and spread over the foliage surface. Application rates are critical. The proper dilution is required to kill the pest. If it is too concentrated, plant damage may occur. Application of control measures should be as instructed by the authentic organization.

Control Options for IPM:

Control options can be arranged by their mode of action and their impact on the environment.

Generally, these are grouped from least to highest impact:

(1) Cultural and mechanical controls,

(2) Biological controls and

(3) Chemical controls (soaps and oils, botanical pesticides and synthetic pesticides).

1. Cultural and Mechanical Controls:

Keeping plants healthy and growing vigorously should be the first line of defense against pests. The next level of control includes hand removal, use of screens, barriers, traps, freezing and crushing. These are excellent options for the home cultivator. Mechanical methods generally have little or no negative effects on the environment.

(a) Hand Removal:

This method is suitable for larger insects. Shake pests into a can that contains a small amount of water and detergent. Scrape off and crush egg masses.

(b) Screens and Barriers:

Any material that is fine enough to keep pests out can be used as a barrier. Screens can keep out large insects, birds and rabbits. Floating row covers well anchored to the ground can prevent attack by nearly all insects. These will also prevent pollination by insects, resulting in lack of fruit.

Cardboard and metal collars will prevent cutworms from reaching young transplants. Sticky bands placed on tree trunks to trap cankerworm and elm leaf beetles. Diatomaceous earth is advertised as a barrier to keep slugs from damaging plants.

The sharp particles, or diatoms, are supposed to cut the slugs' underbody. However, recent reports indicate that it is not effective. The small particle size quickly becomes incorporated into the soil, especially after a rain or irrigation. Copper strips also are offered as a control. They supposedly react with the slugs' slime to shock them.

(c) Trapping:

Traps usually serve as a monitoring system, warning of the presence or increase in undesirable pest numbers. Traps also can be useful in timing control measures. They are sometimes used to control numbers. Yellow, sticky traps attract white- flies, aphids, thrips, leafhoppers and other small flying insects.

Traps that use pheromones or attractive scents to tantalize adult insects are best used as a way to check presence and numbers. Pheromones are used in Japanese beetles traps.

Pitfall traps are cups or jars placed into the ground. Weevils, cutworms and other pests fall into the traps. Light traps capture insects using a black light (ultraviolet). These are used by advanced cultivators to monitor night-flying pests. **"Bug zappers"** are not considered useful because they kill beneficial as well as pests.

(d) Syringing:

A hard stream of water from a hose, washes aphids, spider, mites and other small insects from plant foliage. This must be done frequently since it does not kill insects or eggs. It does not prevent some insects from crawling back onto plants.

2. Biological Controls:

Nearly every species of plant-feeding insect has another insect that is its predator or parasite. Biological methods of control utilize natural enemies of pest insects to keep their populations under control. Biological controls involve several options: predators and parasites, microbes, etc.

(a) Predators and Parasites:

Predatory and parasitoidal insects and mites are often termed "beneficials". Beneficials include predators such as lady beetles, lacewings. syrphid flies, wasps and praying mantises as well as parasitoids, including certain wasps, flies and mites.

There are some parasitoids associated with the larvae of Leucinodes orbonalis (Brinjal pest), they are — Pristomerus testaceus, Cremastus flavoorbitalis, Bracon sp., Shirakia schoenobii and Iphiaulax sp.

Cultivator should learn to recognize beneficial insects. The use of NON SELECTIVE insecticides kills these helpful insects. Rather than trying to introduce beneficial insects into the landscape, avoiding the killing of those that are already there, is a good prescription. A small pest population must continue or the **"beneficial"** will die from lack of food. Purchasing "beneficial" is only recommended for use in greenhouses.

Parasitic insects are less well known than predators, but equally effective. They lay their eggs in a pest species. When the eggs hatch, the larvae feed on the pest insect, killing it. Most of the parasitic insects are tiny wasps.

Many birds and bats eat insect pests. It is advisable to provide water and shelter so as to encourage them to visit your garden.

(b) Microbes:

Bacteria, fungi, viruses, protozoans and parasitic nematodes are microorganisms that attack insects. These microbial "insecticides" are generally effective against very specific pests. As they pose little risk to humans and the environment, microbials are likely to be used more in the future with better preventive measures.

Many cultivators are familiar with a popularly known, microbial-based insecticide called as “Bt” or Bacillus thuringiensis, bacteria which produces a toxin that kills specific caterpillars. The larval pest usually dies within 4 to 7 days. It is a commercially available product (Dipel™, Thuricide™) used to control many kinds of moth and butterfly larvae. There are many STRAINS of “Bt”, each type controlling specific pests.

Parasitic nematodes are very effective against certain pests that live in the soil. However, the nematodes require moist conditions to survive. Few fungi, viruses and protozoa are commercially available, however, these living organisms are difficult to raise, store and apply.

3. Chemical Controls:

Controlling pest by chemical substances is called chemical control and the chemical is called ‘pesticide’. Pesticides are any substances used to kill a pest. “Cide” means to kill; therefore, an insecticide kills insects and an herbicide kills plants. We also have miticides, rodenticides, molluscides, fungicides, etc. Pesticides include repellents, attractants, growth regulators, defoliants, anti-desiccants and antibiotics.

Probable questions:

1. What is Biological Control of pest management? Write down the role of bacteria in pest control.
2. Elucidate different types of biological pest control method.
3. What do you mean by augmentation?
4. What do you mean by Inundation?
5. What do you mean by Importation and inoculation in biological pest control method?
6. Elastrate the general theory of biological pest control.
7. Write down the role of fungi in biological pest control method.
8. Write down the role of viruses in biological pest control method.
9. Write down the role of bacteria in biological pest control method.
10. State the advantages and disadvantages of biological pest control method.
11. What does "IPM" stand for?
12. What is IPM? How it works?
13. Describe briefly four basic steps of Integrated Pest Management (IPM).
14. What kind of methods is used in integrated pest management? Elaborate any one of them.
15. What is the main goal of IPM?
16. Describe the advantage and disadvantages of integrated pest management.
17. What are the limitations of IPM?

Suggested Readings:

1. The Insects by Chapman
2. Modern Entomology by D.B. Thembare
3. Economic Zoology by Shukla and Upadhyay
4. The Insects by Gullan and Carnston
5. Introduction to Economic Zoology by Sarkar, Kundu and Chaki.

UNIT V

Lac culture: Life-history of lac insect, culture method, lac processing, lac products, natural enemies of lac insect and their control

Objective: In this unit we will discuss about life-history of lac insect, its culture method and lac processing, different lac products, natural enemies of lac insect and their control.

Introduction:

Lac culture is the scientific management of lac insects to obtain a high amount of quality lac. This involves selection and maintenance of host plants, inoculation of host plants with healthy lac insects, collection and processing of lac and protection against enemies. Lac is the resinous secretion of lac in- sects. Two species of lac insects *Tachardia lacca* and *T. chinensis* are common, of which the former one is predominant in India. India is the highest lac-producing country. Thailand is next in order.

History:

Lac has been used in India from time immemorial for several purposes, from the epic of Mahabharat it has been recorded that Kauravas built a palace of lac for the destruction of Pandavas. We come across references of lac in the Atharvaveda and Mahabharata, so it can be presumed that ancient Hindus were quite familiar with lac and its uses. Scientific study of lac started much later. In 1709 Father Tachard discovered the insect that produced lac. First of all Kerr (1782) gave the name *Coccus lacca* which was also agreed by Ratzeburi (1833) and Carter (1861). Later Green (1922) and Chatterjee (1915) called the ac- insect as *Tachardialacca* (kerr). Finally, the name was given as *Lacciferlacca*.

Introduction to Lac Insects:

Two strains of the lac insects are recognised in India, RANGEENI and KUSMI. The lac insects that thrive on the host plant Kusum is referred to as Kusmi whereas the Rangeeni strain generally grows on host plants other than Kusum. Each strain completes its life cycle twice a year but the seasons of maturity differ considerably.

There are four lac crops in a year that are named after the Hindi months (Table 1). Lac insects under the genus Kerria are generally bi-voltine with two broods in a year. But few species like *K. lacca* mysorensis (host plant-Sal), and *K. sharda* (host plant-Kusum) are tri-voltine having three broods in a year. Again, species belonging to the genus *Paratachardia* (host plants-Tea, Sandal, etc.,) are all univoltine.

Definition

Lac is a natural resinous secreted by insects called lac insects. Lac culture definition is the scientific management and rearing of lac insects for high-quality lac to be used for commercial purposes is called lac culture. Management involves the selection of host plants, inoculation of plants with lac insects, rearing of lac insects, pest management and harvesting and processing of lac.

Table 1: Strains of lac insect and their characteristics

Characteristics	Kusum	Rangeeni
Host plant	Kusum is main, others include Ber, Siris, Semialata etc.	Rangeeni strains grow well mainly on palas and also on few other tress, but not on kusum
Types of crop	a. Jethwi b. Aghani	a. Kartiki b. Baisakhi

Inoculation time	a. Jethwi: Jan/ Feb b. Aghani: June/July	a. Kartiki: June/July b. Baisakhi: Oct/Nov
Duration of life cycle	a. Jethwi: Jan/ Feb to June/July b. Aghani: June/July to Jan/ Feb	a. Kartiki: June/July to Oct/Nov b. Baisakhi: Oct/Nov to May/June
Harvesting month of crop yield	a. Jethwi: June/July b. Aghani: Jan/ Feb	a. Kartiki: Oct/Nov b. Baisakhi: May/June
Quality of lac	Superior	Inferior to kusumi lac

Taxonomy of Lac Insect: (After E.E.Ruppert and R.D. Barnes, 1994)

Phylum: Arthropoda
Sub-phylum: Uniramia
Class: Hexapoda/Insecta
Subclass: Ectognatha
Order: Hemiptera
Family: Laciferidae
Genus: *Tachardia*
Species: *lacca*

Habit and habit

The lac insects hav bout 113 varieties of host plants have been described and 14 are very common in India. Kusum, Khair, Babul, Ber Palas and Ghont plants give better quality of lac.

Distribution:

India has its monopoly on the production of lac. Other countries like Africa, Australia, Brazil, Burma, Sri Lanka, China, France, W. Germany, Japan, Malaya and several other countries.

Host tree and Strain

Host of major importance

1. Palas – *Butea monosperma*

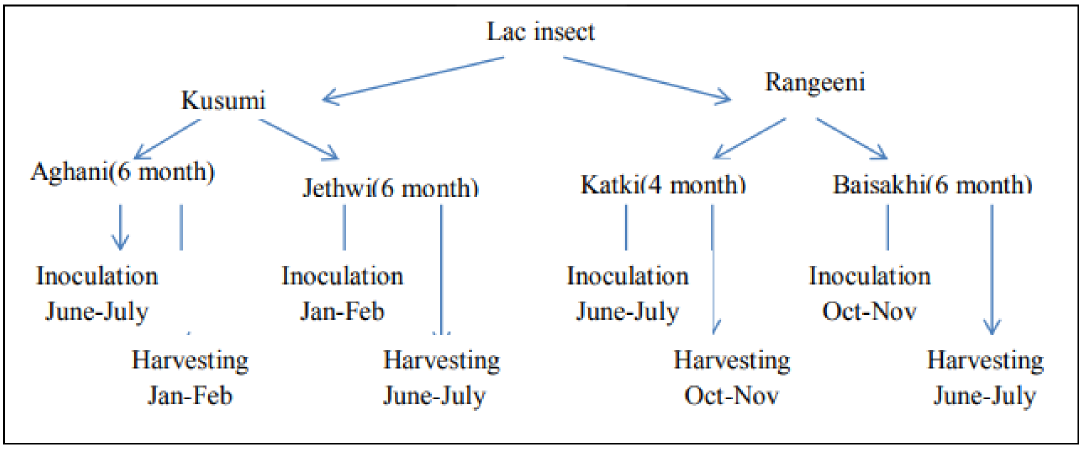
2. Ber – *Zizyphus mauritiana*

3. Kusum – *Schleichera trijuga/oleosa*

4. Kher - *Acacia catechu*

Other host tree includes *Cajanus cajan* (Arhar), *Acacia auriculiformis* (Akashmani), *Zizyphus xylopyra* (Ghont), *Ficus* sp., *Grewea* sp., *Acacia Arabica* (Babul).

Strain of lac insect



The host tree can be divided into three categories based on the type of strain

- Tree on which only kusumi strains can be developed: *Shorea oleosa* (kusum)
- Tree on which only rangeeni strains can be developed: *Butea monosperma* (palas)
- Tree on which both kusmi and rangeeni strain can be developed: *Zizyphus mauritiana* (ber), *Acacia auriculiformis* (akashmani), *Acacia catechu* (khair), *Ficus* sp.
- *Albizia lucida* (Galwang) and *Flemingia semialata* are introduced species of plant on which lac cultivation can be taken up on plantation basis.

Morphology of Lac insect

Lac insect is a hemimetabolous i.e. it undergoes gradual metamorphosis. It has three life stage namely egg, young one and adult. The young ones are called as nymph. The nymphs are similar to adult in all aspects except their size and reproductive organs. The adult male and female are different from each other. Female is about three time larger than the male.

- **Male:** These are pinkish red in colour and may be winged or wing less. Winged male possesses only one pair of translucent membranous forewing. They are mostly found during dry season (Baisakhi and Jethwai). They survive for 3 to 4 days only and die after coupulation. Some of the important characteristics are

i. Head is large, prominent mouthparts but vestigial

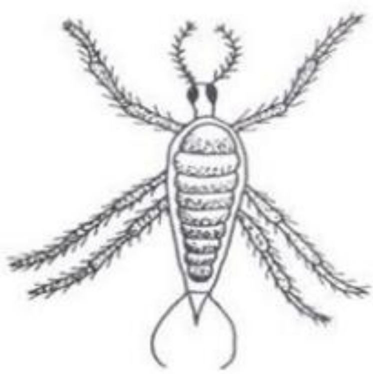
ii. Ocelli are two pairs with seven segmented antennae which have hair on them.

iii. Tarsi 3 segmented.

iv. The abdomen is 8 segmented, broader anteriorly and narrower posteriorly.

v. The last abdominal segment bear pointed penis.


Male with wings


Male without wings

- **Female:** The female is pinkish in colour. The ventral surface of body is flat while dorsal surface is convex. Some of the important characteristics are

i. The female have degenerated eye, legs and wings.

ii. ii. Antennae are vestigial, small and 3 to 4 segmented.

iii. Mouthparts are piercing and sucking type, rostrum is two segmented.

iv. Mesothorax is provided with an appendage on which spiracles open.

v. The abdomen is round and on the dorsal surface, a spine is provided

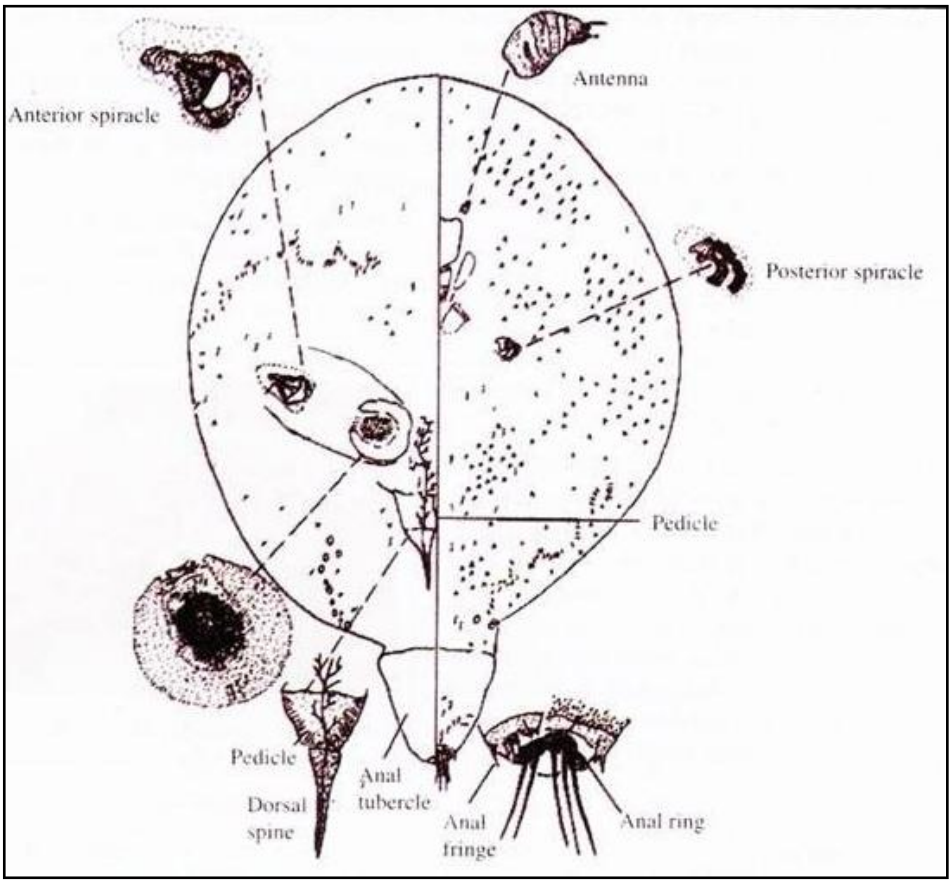


Fig: Diagram of female lac insect (Left half: Dorsal view; Right half: ventral view)

Life Cycle:

Fertilisation: the male adult walks over the female incrustations and inserts itself into the female cells, where it fertilizes the female.

Egg-laying: After fertilization, the female grows rapidly till it becomes capable of egg-laying. A single female lays an average of 200200 to 500500 eggs after fertilization and deposits inside the incubating chambers of the female cell.

Egg Hatching: After 6 weeks, the eggs are hatched into first instar larvae. The mass movement of these larvae in search of a suitable place to suck plant sap is called **swarming**.

Egg: The female lac insect is ovoviviparous in nature. So the laid eggs contain fully developed embryos within it. About 300-1000 such eggs are laid in the chambers (cell) in which the female remains encased. The egg laying period may last from 7 to 10 days. The eggs hatch within few hours of laying. But egg laying ceases if the temperature falls below 17°C in summer and 15°C in winter.

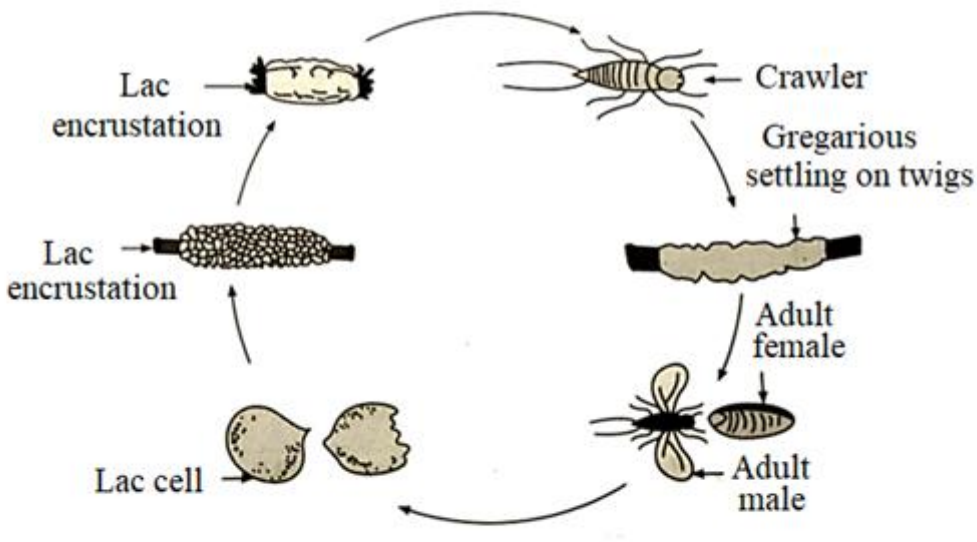


Fig: Life Cycle of Lac Insect

Nymphs: Following hatching, the first instar nymph stays within the cell for a brief period. Then the crimson red coloured nymphs, referred to as 'crawlers', come out of the cell in search of suitable host plant branch for settlement. The emergence of lac insect nymphs in huge number is commonly called swarming that continues for several weeks. Boat-shaped nymphs are very small in size (0.5 mm) and divisible into head, thorax and abdomen. Head bears antennae, ocelli and mouth. Thorax has 3 segments, each with one pair of leg and caudal setae are found at the end of abdomen.

On reaching soft succulent twigs, the nymphs settle down close together and start to suck phloem sap through their suctorial proboscis. After one day or so of settling, the nymphs start secreting lac from the hypodermal glands lying under their cuticle keeping open their mouthparts, breathing spiracles and anus. The secreted semisolid lac hardens on exposure to air and the nymph gets fully covered by the lac encasement, called as lac cell.

Adults: Male larvae develop into male adult insects and are without any mouthparts and thus do not feed. One adult male insect can fertilize several females, and soon after fertilization, it dies. The adult **female** is smaller in size than the male and is without legs and wings. The female larvae never move out of the cell once they settle down after swarming.

Metamorphosis:

Within the cell, the nymphs moult thrice before reaching maturity. During first moult both male and female nymphs lose their appendages, legs and eyes. Following this moult, dimorphism appears in their cells. Inside the male cells, the male nymph casts off their second and third moults and matures into adults.

On maturity, the males lose their proboscis and develop antennae, legs and a pair of wings. The male brood cell is slipper- shaped. It bears a pair of branchial pores on the anterior side and a single large circular pore on the posterior side. The posterior hole remains covered by a round trap door or operculum through which adult males emerge. The female brood cell is larger, globular in shape that remains fixed to the twig. The female cell also has a pair of branchial pore and a single round anal tubular opening through which protrudes waxy white filaments (it indicates that the insect inside the cell is alive and healthy).

These filaments also prevent the blocking of the pore during excess secretion of lac. Following second and third moulting, the females retain only mouthparts but fail to develop any wings, eyes or appendages. While developing into adult, the female becomes immobile and large in size to accommodate huge number of eggs. During development, the females continuously secrete resin at a faster rate that coalesces around its body. After 14 weeks, the females shrink in size allowing light to pass into the cell.

Lac Secretion:

Lac is a resinous substance secreted by certain glands present in the abdomen of the lac insects. The secretion of lac begins immediately after the larval settlement on the new and tender shoots. This secretion appears first as a shining layer which soon gets hardened after coming in contact with air. This makes a coating around the insect and the twig on which it is residing. As the secretion continues the coating around one insect meet and fuses completely with the coating of another insect. In this way a continuous or semi-continuous incrustation of lac is formed on the tender shoots.

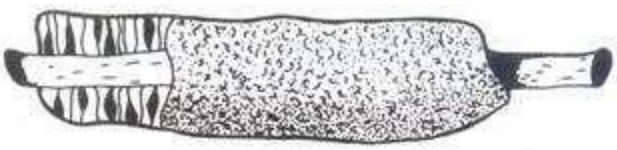


Fig. 36. Lac incrustation.

Cultivation of Lac:

Cultivation of lac involves proper care of host plants, regular pruning of host plant, infection or inoculation, crop-reaping, control of insect pests, and forecast of swarming, collection and processing of lac. The first and perhaps the most important prerequisite for cultivation of lac is the proper care of the host plant. It is the host plants on which lac insects depend for their food, shelter and for completion of their life cycle. There are two ways for the cultivation of host plants. One is that plants should be allowed to grow in their natural way and the function of lac-culturist is only to protect and care for the proper growth of plants.

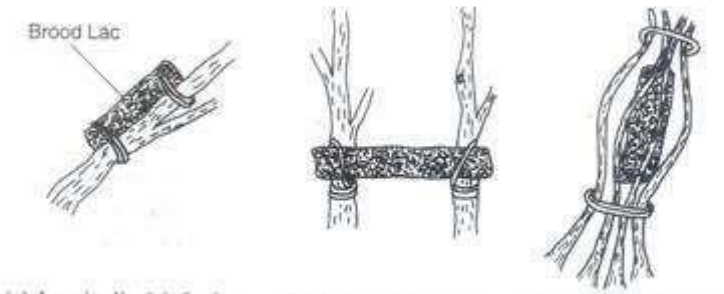
Another way is that a particular piece of land is taken for the purpose and systematic plantation of host plant is made there. Regular watch is necessary in this case by providing artificial manures, irrigation facilities, ploughing and protecting the plants from cattle and human beings for which the land should be fenced. The larvae of lac insects are inoculated on host plants only after the host plants have reached a proper height.

The lac larvae feed on the cell sap by inserting their proboscis in the tender twigs. The proboscis can only be inserted in the tender young off-shoots. For this before inoculation, pruning of lac host plants is necessary. The branches less than an inch in diameter are selected for pruning. Branches half inch of less in diameter should be cut from the very base of their origin. But the branches more than half inch diameter should be cut at a distance of 1 ½ inch from the base.

i. Inoculation:

The method by which the lac insects are introduced to the new lac host plant is known as inoculation. This may be of two types, namely "Natural infection" and "Artificial infection". When infection from one plant to other occurs by natural movements of insect, it is called natural infection. This may be due to overcrowding of insect population and non-availability of tender shoots on a particular tree.

Artificial infection takes places through the agencies other than those of nature. Prior to about two weeks of hatching, lac bearing sticks are cut to the size of six inches. They are called"Brood lac". Brood lacs are then kept for about two weeks in some cool place.



(a) Longitudinal infection (b) Lateral infection (c) Interlaced infection

Fig. 37. Three different ways of artificial inoculation of lac.

When the larvae start emerging from this brood lac, they are supposed to be ready for inoculation. Strings can be used for tiding the brood lac with the host plant may be of different types in longitude infection the brood lac is tied in close contact with host branches. In lateral infection the brood lac is tied across the gaps between two branches. In interlaced method, brood lac is tied among the branches of several new shoots.

ii. Scraping and Processing of lac:

Lac cut from the host plant is called as "stick lac". Lac can be scraped from the twigs before or after the emergence of larvae. If it is used for manufacturing before the emergence of larvae, the type of lac produced is called as "Ari lac" and if it is used for manufacturing purpose after swarming of larvae has occurred, the lac is said to be Phunkilac". The scraping of lac from twig is done by knife, after which they should not be exposed to sun. The scraped lac is grinded in hard stone mills. The unnecessary materials are sorted out In order to remove the finer particles of dirt and colour, this lac is washed repeatedly with cold water. Now at this stage it is called as "Seed lac" and is exposed to sun for drying. Seed lac is now subjected to the melting process. The melted lac is sieved through cloth and is given the final shape by moulding. The final form of lac is called "Shellac". Colour or different chemicals may be mixed during melting process for particular need.

iii. Preparation of Feeding Ground for Lac Insects:

To get good quality lac through cultivation, it is necessary to ensure proper type of feeding ground to the lac insects. The insects need to be provided with succulent shoots, as it cannot drive its slender proboscis through thick bark. For getting a good number of requisite succulent shoots, the most important method is pruning.

iv. Pruning:

Pruning means cutting away old, weak and diseased twigs from the host plants. It is done in January or June. It is very important for cultivation as it induces the host plants to throw out new succulent twigs. Pruning should be done with a sharp instrument to give a short and neat cut. If trees are old and have lost their capacity to produce vigorous shoots of new flush, heavier pruning is carried out to produce the new wood at the expense of the old. Such operation will bring the tree to a better shape, so that subsequent pruning will give the desired flush. Proper pruning should result in a good shape and give plenty of chances for the development of new shoots.

Objectives of Pruning:

1. To ensure new, good, healthy and succulent shoots.
2. To ensure availability of large number of shoots (larger area for lac insect settlement).
3. To provide rest to host plant for maintaining its vigour.
4. To remove dead, diseased and broken branches.

Types of Pruning in Lac Host Plants:

Two types of pruning have been recommended for lac culture.

(i) Apical/ light pruning:

Branches less than 2.5 cm diameter should be cut from base and branches more than 2.5 cm diameter should be sharply cut leaving a stump of 30-45 cm from the base. Diseased and dead portion of branches should be removed completely. Light pruning is recommended for slow growing conventional host tree species like Palas, Kusum and Ber.

(ii) Basal / heavy pruning:

Branches having less than 7cm thickness should be removed from the base, whereas thicker branches should be cut at a place where it has a diameter of 7 cm. In quick growing bushy host, pruning should be done at a height of 10-15 cm from the ground level, e.g., *Flemingia macrophylla, F. semialata*.

Pruning time:

After several years of experiment done at Indian Lac Research Institute (presently I.I.N.R.G.). Ranchi, Jharkhand, it has been found that the best results are obtained by pruning in February for raising the Kartiki crop and in April for raising the Baisakhi crop of Rangeeni for host plants Ber and Palas. Pruning in these months will give shoots of four and six months old respectively, for the lac larvae to feed on.

In case of Kusum, pruning is best done in the month of June-July and January- February. These months coincide with those in which the crops mature, and so, harvesting of the mature crop serves the purpose of pruning also. Pruning time will, however, need to be adjusted to suit local conditions.

Use of Lac:

Lac has been used for the welfare of human beings from the great olden days No doubt the development of many synthetic products have made its importance to a little lesser degree, but still it can be included in the list of necessary articles. Lac is used in making toys, bracelets, sealing wax, gramophone records etc.

It is also used in making grinding stones, for filling ornaments, for manufacturing of varnishes and paints, for silvering the back of mirror, for encasing cable wires etc., Waste materials produced during the process of stick lac is used for dying purpose. Nail polish is a good example of the by-product of lac.

Composition of Lac:

Lac is a mixture of several substances, of which resin is the main constituent. The approximate percentage of different constituents of lac is given below:

Resin – 68 to 90%
Dye – 2 to 10%
Wax – 5 to 6%
Mineral matter – 3 to 7%
Albuminous matter – 5 to 10%
Water – 2 to 3%

Lac Crop:

The lac insects repeat its life cycle twice in a year. There are actually four lac crops since the lac insects behave in two ways either they develop on Kusum plants or develop on plants other than Kusum. The lac which grows on Non-Kusum plants is called as "Ranjeem lac," and which grows on Kusum plant is called as "Kusumi lac. Four lac crops have been named after four Hindi months in which they are cut from the tree. They are as follows:

A. Ranjeeni Crop:

i. Kartiki:

Lac larvae are inoculated in June-July. Male insect emerges m August-September. Female give rise to swarming larvae in October-November and the crop is reaped in Kartiki (October and November).

ii. Baisakhi:

Larvae produced by Katki crop are inoculated in October-November, male insects emerges in February-March, females give rise to swarming larvae m June-July, the crop is reaped in Baisakh (April-May).

B. Kusumi Crop:

i. Aghani:

Lac larvae are inoculated in June-July, male insect emerges in September, female give rise to swarming larvae in January-February and crop is reaped in Aghan (December-January).

ii. Jethwi:

The larvae produced by Aghani crop is inoculated in the month of January- February, male emerges in March-April, female give rise to swarming larvae in June- July and the crop is reaped in the month of Jeath (June-July).The time of infection with swarming larvae, the time of emergence of male insects, the time of reaping the crop, and the time of producing swarming larvae by female etc., are shown m tabular form below

Infection with swarming larvae	*Emergence of male insect*	*Crop reaped*	*Female give rise to swarming larvae*
Ranjeeni or Nankusumi Crop			
Katki (June-July)	August	Oct.-Nov.	Oct.-Nov.
Baisakhi (Oct.-Nov.)	Feb.-March	April-May	June-July
Kusumi Crop			
Aghani (June-July)	September	Dec.-Jan.	Jan.-Feb.
Jethoi (January)	March-April	June-July	June-July

Enemies of Lac Insects and their Control:

There are many natural enemies of lac insects which include vertebrates, invertebrates (insect predators and parasites) and microbial flora.

A. Vertebrate enemies of lac insects:

The important vertebrate enemies are squirrels and rats. In worst conditions, the damage caused by these enemies can be as serious as 50% of brood sticks. Squirrels are active during the daytime and the damage by them is more common under forest conditions. Rats are active at night-time and the damage usually occurs near about the villages.

Towards the crop maturity, these pests gnaw the mature lac encrustation on the tree, damage the brood lac tied to trees for inoculation and consume the full grown gravid female lac insects. The damage to brood lac tied to trees interferes with the inoculation, as the brood bundles and the lac encrustations drop to the ground where the larval emergence is taking place. Besides squirrels and rats, monkeys also cause some damage to lac encrustations and to the newly developing shoots from pruned host trees by breaking them.

Control:

It is difficult to control the squirrels and rats under the open field conditions where lac is cultivated. However, scaring away of these animals or poisoning them may be adopted to keep the rodents under attack.

B. Insect enemies of lac insect:

It has been estimated that on an average, up to 30-40% of the lac cells are destroyed by insect enemies of lac crop. At times, the enemy attack can be so serious as to result in total crop failure.

There are two kinds of enemy insects:

i. Parasites, and

ii. Predators.

Parasites:

All parasites causing damage to lac insect belong to the Order Hymenoptera of class Insecta. A list of parasites associated with lac insect, *Kerria lacca* is presented in Table 4.4.

Table 4.4 : Some important Parasites and Predators of lac insect

Parasite of lac insects	Family	Predators of lac insects	Family
Anicetus dodonia	Encyrtidae	*Eublemma amabilis* (Fig. 4.19)	Noctuidae
Atropates hautefeuilli	Encyrtidae	*E. coccidiphaga*	Noctuidae
Aphrastobracon flavipennis	Encyrtidae	*E. cretacea*	Noctuidae
Bracon greeni (Fig. 4.20)	Encyrtidae	*E. scitula*	Noctuidae
Campyloneurus indicus	Encyrtidae	*Pseudohypatopa pulverea*	Blastobasidae
Coccophaqus tchirchii (Fig. 4.21)	Aphelinidae	*Catablemma sumbavensis* (Fig. 4.22)	Blastobasidae
Erencyrtus dewitzi	Encyrtidae	*Cryptoblabes ephestialis*	Blastobasidae
Eupelmus tachardiae (Fig. 4.23)	Eupelmidae	*Phroderces falcatella*	Cosmopterygidae
Eurymyiocnema aphelinoides	Aphelinidae	*Lacciferophaga yunnanea*	Momphidae
Lyka lacca	Encyrtidae	*Chrysopa madestes*	Chrysopidae
Marietta javensis	Aphelinidae	*C. lacciperda*	Chrysopidae
Parageniaspis indicus	Encyrtidae	*Berginus maindroni*	Mycetophagidae
Parechthrodryinus clavicornis	Encyrtidae	*Silvanus iyeri*	Cucujidae
Protyndarichus submettalicus	Encyrtidae	*Tribolium ferrugineum*	Tenebrionidae
Tachardiaephagus tachardiae	Encyrtidae	*Phyllodromia humbertiana*	Blattellidae
Teachardiobius nigricans	Encyrtidae	*Ishonoptera fulvastrata*	Blattellidae
Aprostocetus (Tetrastichus) purpureus (Fig. 4.24)	Eulophidae	*Dolichoderus thoracicus*	Formicidae

Among the parasites listed, *Tachardiaephagus tachardiae* and *Tetrastichus purpureus* are the most abundant lac associated parasites. They lay their eggs in the lac cells and the grubs (larvae) after hatching start to feed on the lac insect within its cell.

Predators:

The predators, on the other hand, are more serious and may cause damage up to 30-35 per cent to the cells in a crop. The important predators of lac insects are listed in Table 4.4. Of the predators, *Eublemma amabilis* and *Pseudohypato papulverea* are the most destructive to lac insects and are in regular occurrence but their incidence may vary from season to season, place to place and crop to crop.

Prevention and Control of Insect Enemies:

Preventive measures:

a) Parasite- and predator- free brood lac should be used for inoculation.
b) Self-inoculation of lac crops should be avoided as far as possible.
c) Inoculated brood bundles should be kept on the host tree for a minimum period only.
d) Phunki (empty brood lac sticks) should be removed from the inoculated trees in 2-3 weeks time.
e) All lac cut from the tree and all phunki brood lac (after use as brood lac) not required for broodpurpose should be scraped or fumigated at once.
f) Cultivation of Kusmi strain of lac should be avoided in predominantly Rangeeni area and viceversa.

Mechanical control:

Use of 60 mesh synthetic netting (brood bag) to enclose brood lac for inoculation purposes can reduceinfestation of enemy insects of lac.

The emerging lac larvae easily crawl out from the minute pores of the net and settle on the twigs of the lac host plants, whereas the emerging adult predator enemies cannot move out of the brood bags and get entrapped within the net. This can check the egg laying by the predator moths on the newcrop.

Chemical control:

Application of 0.05% endosulphan at 30-35 days stage of crop has been identified as the most effective dose of insecticide without any adverse effect on the economic attributes of the lac insect.

Microbial control:

Use of bio-pesticide, Thuricide (*Bacillus thuringiensis*) at 30-35 days stage of crop is the effective microbial control measure for important enemy insects of lac in field condition.

Biological control:

Two ant predators, viz. *Camponotus compresus* and *solenopsis geminate*, are the most important and promising for biological control of predator enemies of lac in field condition. Egg parasitoids, viz. *Trichogramma pretiosum, T. chilonis, T. poliae, Trichogrammatoideabactrae* and *Telenomus remits*, have been found to be effective in management of many lac predators like *P. pulverea*.

Again, hyperparasitism is found to happen in some lac cultivation areas where parasites of lac insects could also be controlled biologically by hyperparasitic insects, viz., *Aprostocetus (Tetrastichus) purpureus* (Fig. 4.24) is secondary parasite of *Coccophaqustchirchii* (Fig. 4.21), and *Eupelmustachardiae* (Fig. 4.23) is a secondary parasite of *Eublemmaamabilis*.

Fig. 4.21. *Coccophaqus tchirchii*, a parasite of lac insect

Fig. 4.22. *Catablemma sumbavensis*, a parasite of lac insect

Fig. 4.23. *Euplemus tachardiae* a parasite of lac insect

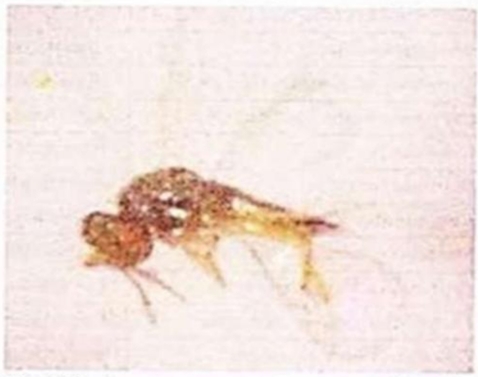


Fig. 4.24. *Aprostocetus purpureus*, a parasite of lac insect

Microbial Flora Associated with Lac Insects:

Two types of microflora, viz. bacteria and fungi, are associated with the lac insects. Bacteria could be symbiotic or pathogenic. Microbial studies revealed that four species, viz. *Micrococcus varians. M. conglomerates, Clostridium sp.* and *Bacillus subtilis*, are found in permanent association with various stages of lac insects. Presence of various symbiotic microflora is considered beneficial for good yield of lac, particularly during rainy season crop. However, on the other hand, association of fungi with lac insect is not always beneficial.

Fungal infection in lac culture causes severe losses of lac yield by:

a) Killing the lac insects by inhibiting respiration.
b) Hindering mating process.
c) Blocking larval emergence.
d) Affecting lac host efficiency.

Lac culture during rainy season is prone to fungal attack particularly when grown on Ber and Kusum trees due to their steady and spreading crown. Three species of fungi belonging to family Eurotiaceae and Aspergillaceae, viz. *Aspergillus awamori, Aspergillus terricola* and *Penicillium citrinum,* are reported to cause maximum loss in lac crop. *Aspergillus awamori* (Fig. 4.25) and *Penicillium citrinum* are black and greenish in colour respectively, and make a continuous cover on lac insect cells and thereby blocking their breathing pores which ultimately lead to mortality of lac insects. A pathogenic fungus, *Pythium* sp. in female tests, causes a heavy mortality of the larvae which fail to enclose satisfactorily and lie dead in clusters within the female resinous cells.

Fig. 4.25 Fungal-cover on lac encrustation

Prevention and control:

Application of fungicides, Bavistin (carbendazim 0.05%) and Dithane M-45 (mancozeb, 0.18%) by both dipping of brood lac before inoculation and spraying on standing crop gives significantly better yield of lac. Significant reduction (84% to 75%) in mortality of 2nd instar lac nymphs/larvae can be done by the application of different concentrations of carbendazim and aureofungin on Kusumi stain of lac insects.

Present Position of this Industry in India:

Lac is produced in a number of countries including India, Thailand, Mayanmar, China, Indonesia, Vietnam and Laos. India and Thailand are the major producers, producing on the average 1700 tonnes of lac annually, followed by China. India alone, accounts for about 70/o of global lac production.

Former Bihar is the most important lac producing state of India. The Indian council of Agriculture Research has established Indian Lac Research Institute at Namkum in Ranchi district of Jharkhand.The average of different states in the total quantity of stic lac produced in this country is given below:

Bihar – 55.5%, Madhya Pradesh – 22% ,West Bengal – 10%, Maharashtra – 7.1%, Gujrat – 2.7% , Uttar Pradesh – 1.8%, Assam – 0.6% and Orissa – 0.1%

Total annual global production of pure lac is estimated to be 20,000 tonnes. The average total production of stick lac in India is about 24,000 tonnes, while the annual average pure lac produced in the country is 11,890 tonnes. About 6000 tonnes of pure lac produced in India is exported to different countries of the world, with an average earning of Rs. 202.38 million in term of foreign exchange. It has been estimated that 3-4 million people mostly tribals are engaged in the cultivation and several thousands in addition are engaged in the trade and manufacture of lac. Two main competitors of Indian lac are (i) Thailac, which accounts 50% of the total lac exported, and (ii) Synthetic resion, which have replaced lac in certain field. Shellac being a versatile resion, there is immense scope of increasing its utilisation in various fields and there is also scope to modify it to meet particular need.

Probable questions:

1. What is lac? Describe its composition and uses.
2. Describe structure of a male and female lac insect.
3. Write down the life cycle of lac insect with suitable diagram.
4. What are different types of Ranjeeni crops?
5. What are different types of Kusumi crops?
6. What is prunning? What are the objectives of prunning?
7. Describe types of prunning in lac host plant.
8. What is the present status of lac culture in India?
9. Describe different parasites in lac culture. Also state their control measures.
10. Describe different predatores in lac culture. Also state their control measures.

Suggested Readings:

1. The Insects by Chapman
2. Modern Entomology by D.B. Thembare
3. Economic Zoology by Shukla and Upadhyay
4. The Insects by Gullan and Carnston
5. Introduction to Economic Zoology by Sarkar, Kundu and Chaki.
6. A textbook of Economic Zoology by Aminul Islam

UNIT VI

Sericulture: Indigenous races, pure races and commercial races of mulberry silk moth; rearing of mulberry silk moth

Objective:

In this unit we will discuss about Indigenous races, pure races and commercial races of mulberry silk moth; rearing of mulberry silk moth.

Introduction:

Silk production has a long history. Silk was discovered by Xilingji (Hsi-ling-chi), wife of China's 3rd Emperor, Huangdi (Hoang-Ti), in 2640 B.C. While making tea, Xilingji accidentally dropped a silkworm cocoon into a cup of hot water and found that the silk fiber could be loosened and unwound. Fibers from several cocoons could be twisted together to make a thread that was strong enough to be woven into cloth. Thereafter, Hsiling chi discovered not only the means of raising silk worms, but also the manners of reeling silk and of employing it to make garments. Later sericulture spread throughout China, and silk became a precious commodity, highly sought after by other countries. Demand for this exotic fabric eventually created the lucrative trade route, the historically famous Silk Road or Silk Route named after its most important commodity. This road helped in taking silk westward and bringing gold, silver and wool to the East. With the mulberry silk moth native to China, the Chinese had a monopoly on the world's silk production. After 1200B.C. Chinese immigrants who had settled in Korea helped in the emergence of silk industry in Korea. During the third century B.C. Semiramus, a general of the army of Empress Singu-Kongo, invaded and conquered Korea. Among his prisoners were some Sericulturists whom he brought back to Japan. They helped in the establishment and growth of sericulture industry in Japan. Another story is that a Chinese princess married an Indian prince. She carried silkworm eggs/mulberry cocoons in her elaborate head dress. She disclosed the secret of raising silkworms thus, silk production spread in India. In 550A.D. moth eggs and mulberry seeds were smuggled from China by two Nestorian monks, sent by Emperor Justinian-I and silk production began in Byzantium. The technique of sericulture spread throughout the Mediterranean countries during the 7th century AD and then to Africa, Spain and Sicily. During latter part of the 19th century, modern machinery, improved techniques and intensive research helped the growth of sericulture industry in Japan. At present, Japan, China, Korea, Italy, Soviet Union, France, Brazil and India are the chief silk producing countries in the World.

Silk has been under use by human beings for various purposes since ancient times. Pure silk is one of the finest and most beautiful natural fibres of the world and is said to be “the queen of fibres. One of the methods was the rearing of silkworms on large scale with great care in natural and controlled conditions. Different rearing techniques are applied in different parts of the world for large scale production of silk threads of fine quality. This is known as sericulture.

Types of Silk:

Moths belonging to families Satumidae and Bombycidae of order lepidoptera and class Insecta produce silk of commerce. There are many species of silk-moth which can produce the silk of commerce, but only few have been exploited by man for the purpose. Mainly four types of silk have been recognised which are secreted by different species of silk worms.

(i) Mulberry Silk: This silk is supposed to be superior in quality to the other types due to its shining and creamy white colour. It is secreted by the caterpillar of *Bombyx mori* which feeds on mulberry leaves.

(ii) Tasar Silk: It is secreted by caterpillars of *Antheraea mylitta*, *A. paphia, A. royeli, A. pernyi, A. proyeli* etc. This silk is of coppery colour. They feed on the leaves of Arjun, Asan, Sal, Oak and various other secondary food plants.

(iii) Eri Silk: It is produced by caterpillars of *Attacus ricini* which feed on castor leaves. Its colour is also creamy white like mulberry silk, but is less shining than the latter.

(iv) Munga Silk: It is obtained from caterpillars of *Antheraea assama* which feeds on Som, Champa and Moyankuri.

Voltinism:

Voltinism refers to the number of breeds raised per year. Voltinism is a genetically determined heritable character under hormonal control. Based on voltinism *B.moriis* divided into three type of races: univoltines, bivoltines, and poly or multi-voltines.

1. **Univoltine** races produce only one generation per year. The eggs laid remain in a diapausing (quiet) condition till the next spring. Larvae of univoltines are very sensitive to temperature and other environmental conditions. They are unsuitable for summer and autumn rearing by artificial breaking of egg diapause. The larval period is very long. All European races are Univoltines. The cocoons produced are commercially very superior.

2. **Bivoltine** races have two generations per year, the first generation adults developing from eggs hatched in spring lay non dipausing eggs. The second generation

adults developing from these eggs lay eggs which remain in the dormant state till next spring. The larval duration is as long as univoltines. Larvae are robust and tolerate environmental fluctuations. They can be used for 'summer and autumn rearing and three crops can be raised per year. The cocoons are commercially superior. Japanese and Chinese races have both uni and bivoltine varieties.

3. **Multi or polyvoltines** have more than three generations per year. The larval duration is short, and larvae are resistant to high temperature and high humidity. Larvae and cocoons are small in size. Commercially cocoons are of poor quality. The adults lay nondiapausing eggs.

Taxonomy:

Silk producing insects are commonly referred to as serigenous insects. Silkworm is a common name for the silk-producing caterpillar larvae of silk moths.

Silk moths belong to

Phylum – Arthropoda

Class – Insecta

Order – Lepidoptera

Super family - Bombycoidea.

Bombycoidea comprises eight families of which only Bombycidae and Saturnidae are the two important families the members of which produce natural silk. There are several species of silkworm that are used in commercial silk production .These are:

(i) Mulberry silk worm

- *Bombyx mori* (Bombycidae)
- *Bombyx mandarina* (Bombycidae)

(ii) Tasar silk worm

- *Antheraea mylitta* (Saturnidae)
- *Antheraea pernyi* (Saturnidae)
- *Antheraea yamamai* (Saturnidae)
- *Antheraea paphia* (Saturnidae)
- *Antheraea royeli*(Saturnidae)

(iii) Muga Silkworm

- *Antheraea assama* (Saturnidae)

(iv) Eri silk worm

- *Philosamia ricini* (Saturnidae)

BREED: A stock of animals or plants within a species having a distinctive appearance and typically having been developed by deliberate selection.

RACES: A population within a species that is distinct in some way, esp. a subspecies.

Indigenous originating in and characteristic of a particular region or country; native. Eg., Pure Mysore, Nistari.

Exotic plant or animal species introduced into an area where they do not occur naturally, nonnative species. Eg., E16, Daizo etc.

Classification based on geographic distribution

1. Japanese race (aboriginal in japan): Fecundity is higher ranging from 600-700. The larvae are very active and leaf cocoon ratio is less. Larval body size is small for long larval duration & is around 26 days and the larvae are marked. The shape of the cocoon is strangulated giving the appearance of pea nut shape. Almost all races produce white cocoons. Further, Percentage of double cocoons is more and quality of silk is better. Larvae are susceptible to grasserie and flacherrie. There are Uni and Bivoltines races in this group.

2. Chinese race (aboriginal in china): In Chinese races the fecundity rate is higher ranging from 600- 650 eggs. The progress of the larval growth is quick & as a result of which the leaf cocoon ratio is less. Most of the Chinese races are plain without any markings. The shape of the cocoon is round/elliptical/few of them are spindle shaped. The Cocoon colour is white, golden yellow, flesh or red. The Silk filament is fine and reelability is good. The Chinese races are resistant to high temperature & humidity. Uni, Bi, Multivoltines falls under this group and ever trimoulters are noticed.

3. European races (aboriginal in europe and central asia): The fecundity rate is medium ranging from 550- 600 & size of the eggs is large. The larval stage is long, the moulting period reduced by 1-2 h. The larvae are plain without any markings. The cocoons are big, long elliptical. Cocoons are either white/flesh coloured. The % of double cocoons is less. The filament length is long with good reelability. Europian races are weak against high temperature & humidity. All are Univoltines.

4. South east asian races (tropical): The fecundity rate is lower ranging from 400-500. Eggs are small. The larval length is short with few exceptions where the tropical races of India exhibit longer larval duration. The larval markings are not common in these races. Leaf cocoon ratio is high. The size of the larvae is small. The shape of the cocoon is spindle, flossy with less filament length. The common cocoon colour is green/pink/yellow/white. Denier of the silk filament is fine. These races are resistant to varied environmental conditions especially high temperature & humidity. Multivoltines/polyvoltine races are very common.

Mulberry Culture:

- **Biology of Mulberry Silkworm:**

The insect producing mulberry silk is a domesticated variety of silkworms, which has been exploited for over 4000 years. All the strains reared at present belong to the species B*ombyx mori* that in believed to be derived from the original Mandarina silkworm, *Bombyx mandarina* Moore. China in the native place of this silk worm, but now it has been introduced in all the silk producing countries like Japan, India, Korea, Italy, France and Russia.

The races of mulberry silk worm may be identified on the basis of geographical distribution as Japanese, Chinese, European or Indian origin; or as Uni-, Bi- or Multivoltine depending upon the number of generations produced in a year under natural conditions; or as Tri-, Tetra- and Penta- moulters according to the number of moults that occur during larval growth; or as pure strain and hybrid variety according to genetic recombination.

- **Life Cycle:**

Life cycle of the silkworm consists of four stages i.e. adult, egg, larva, and pupa. The duration of life cycle is six to eight weeks depending upon racial characteristics and climatic conditions.

- **Life history of mulberry silk worm, *Bombyx mori* (L) :**

The adult of Bombyx mori is about 2.5 cm in length and pale creamy white in colour. The entire body is covered with scales. The males have longer antennae and narrow abdomen while the female has small antennae, large and flat abdomen and is less active than the male. Due to heavy body and feeble wings, flight is not possible by the moth. This moth is does not feed during its very short life period of 2-3 days.

✓ **<u>Fertilization:</u>** Fertilization is is internal preceded by copulation. Just after emergence male moth copulates with female for about 2-3 hours and if not separated they may die after few hours of copulating with female.

✓ **<u>Egg laying:</u>** Just after fertilization, female starts egg laying which is completed in 1-24 hours. One moth lays 400-500 eggs depending upon the climatic conditions and the supply of food material to the caterpillar from which the female moth is obtained. The egg is laid in form of clusters and covered with gelatinous secretion of the female moth which helps them in proper attachment.

✓ **<u>Egg:</u>** The eggs laid by the female moth are rounded and white in colour. The weight of the newly laid 2,000 eggs comes to about 1 gm. With the increase in time after laying. Eggs become darker. Two types of eggs are generally found viz., Diapause type and Non-Diapause type.

✓ **<u>Hatching:</u>** The eggs after ten days of incubation hatch into a larva called as caterpillar. Hatching is the most important phase of silk moth life. After hatching caterpillars need continuous supply of food because they are voracious feeders. It proper supply of mulberry leaf is not possible the development of caterpillar would not be in a proper curse. Sometimes, due to lack of food material, young caterpillars die causing great loss to the sericulture industry.

✓ **<u>Caterpillar:</u>** The newly hatched caterpillar is about 1/8th of an inch in length and is pale, yellowish white in colour. The caterpillars are provided with well developed mandibulate biting and chewing type of mouth-parts adapted to feed easily on the mulberry leaves. The caterpillar is twelve segmented and the abdominal region has ten segments having five pairs of pseudo-legs. It is also provided with a small dorsal horn on very soft leaves of mulberry plants. As they are voracious feeders, they grow rapidly which is marked by four moultings. After 1st, 2nd, 3rd and 4^{th} moulting caterpillars get changed into 2nd, 3rd, and 4th, 5th instars respectively. It takes about 21 to 25 days after hatching. The full grown caterpillar is 7.5 cm in length. It develops salivary glands, stops feeding and undergoes pupation. The time taken for the full growth of the caterpillar from young to the well grown stage varies with regard to the temperature, humidity, food supply and type of race. The weight of the full grown caterpillar varies from 4 to 6 gm.

✓ **<u>Pupa:</u>** The caterpillars stop feeding and move towards corner among the leaves and secrete a sticky fluid through silk gland. The secreted fluid comes out through spinneret (a narrow pore situated on the hypopharynx) and takes the form of long fine thread of silk which hardens on exposure to the air and wrapped around the body of the caterpillar in the form of covering called as Cocoon.

✓ **Cocoon:** Cocoon is the white coloured bed of the jpujpa whose outer threads are irregular while the inner threads are regular. The length of continuous thread secreted by a pupa for the formation of cocoon is about 1000-1200 metres which requires 3 days to complete. The thread is wound around the cocoon in concentric manner. The binding of threads round the cocoon is achieved by the constant round motion of the head of the pupa from one side to the other at the rate of 65 times per minute. The weight of one cocoon is about 1.8 to 2.2 gm and the weight of the cocoon shell only is 0.45 gm. The size of the thread is 2.0 to 2.8 denier. The pupal period lasts for 10 to 12 days and the pupae cut the cocoon and emerge into adult moths.

Emergence of imago: Due to active metamorphic changes during pupation period the abdominal pseudo-legs disappear and two pairs of wings develop. The silk worm within the cocoon secretes an alkaline fluid to moisten its one end. The moistened end becomes soft where the threads are cut open by the silk.

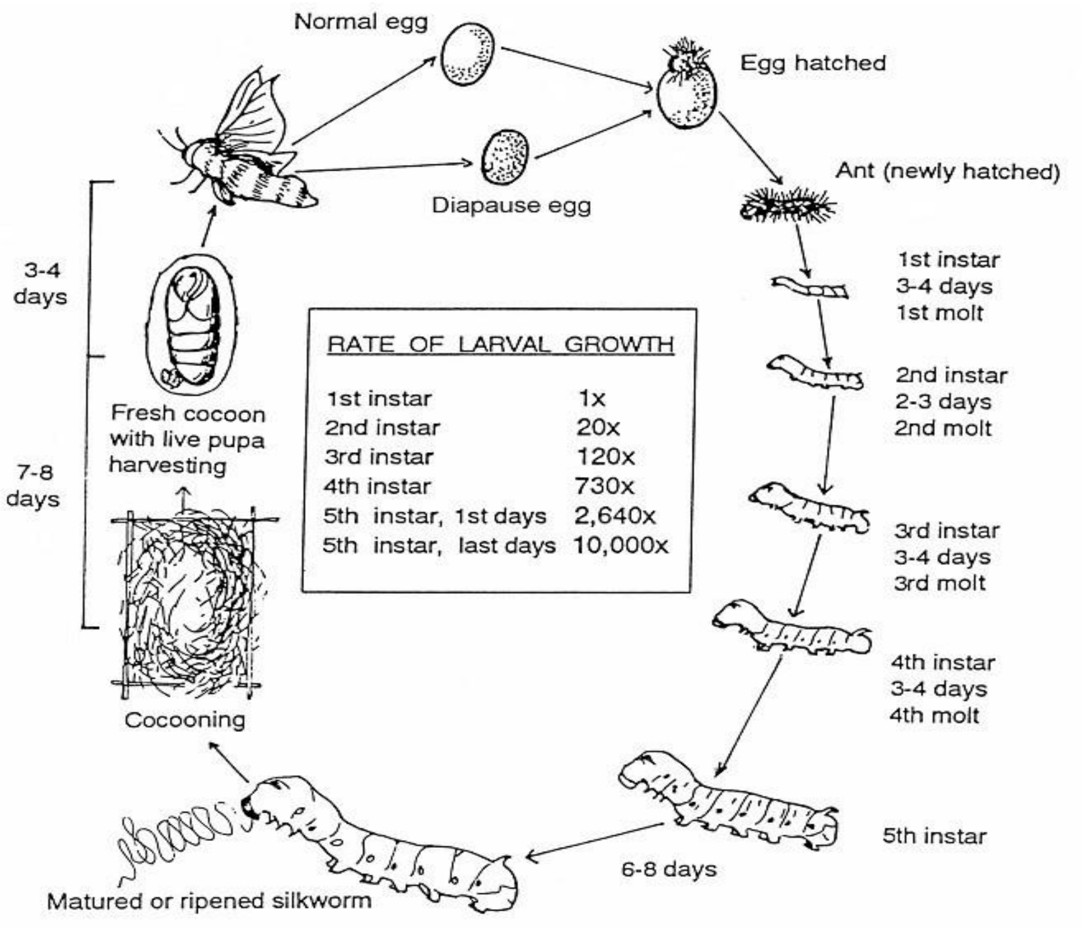


Fig: Life cycle of *Bombyx mori*

• Sericulture and its components:

Commercial rearing of silk producing silkworm is called sericulture. It is an agro-based industrycomprising three main components:

i) Cultivation of food plants of the worms,

ii) Rearing of silk worms, and

iii) Reeling and spinning of silk.

The first two are agricultural and the last one is an industrial component. There are four varieties of silkworms in India, accordingly sericulture is classified into Mulberry Culture, Tasar Culture, Muga Culture and Eri Culture, and each one is described separately in the following text.

• Cultivation of food plants of the worms Mulberry Cultivation (Moriculture):

Cultivation of mulberry plants is called moriculture. There are over 20 species of mulberry, of which four are common: *Morus alba, M. indica, M. serrata* and *M latifolia*. Mulberry is propagated either by seeds, root- grafts or stem cuttings, the last one being most common. Cuttings, 22-23 cm long with 3-4 buds each and pencil thick, are obtained from mature stem. These are planted directly in the field or first in nurseries to be transplanted later. After the plants have grown, pruning is carried out routinely which serves two purposes, induction of growth and sprouting of new shoots.

Harvesting of leaves for feeding larva is done in three ways: leaf picking, branch cutting and top shoot harvesting. In leaf picking, individual leaves are handpicked. In branch cutting method, entire branch with leaves are cut and offered to 3rd instar larva. In top shoot harvesting, the tops of shoots are clipped and given to the 4th & 5th instars. The yield and quality of leaf depend upon the agronomic practices for cultivation of mulberry trees, namely irrigation, application of fertilizers etc. It is estimated that 20,000 to 25,000 kg of leaves can be harvested per hectare per year under optimum conditions. It has also been estimated that to rear one box of 20,000 eggs, 600-650 kg of leaves are required for spring rearing and 500-550 kg for autumn rearing in Japan. In India, to rear 20,000 eggs the quantity of leaves required is about 350-400 kg.

• Rearing of Mulberry Silkworm :

Cultivation of mulberry plants is called moriculture. There are over 20 species of mulberry, of which four are common: *Morus alba, M. indica, M. serrata* and *M latifolia*. Mulberry is propagated either by seeds, root- grafts or stem cuttings, the last one being most common. Cuttings, 22-23 cm long with 3- 4 buds each and pencil thick, are obtained from mature stem. These are planted directly in the field or first in nurseries to be transplanted later. After the plants have grown, pruning is carried out routinely which serves two purposes, induction of growth and sprouting of new shoots.

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Rearing Equipment:

i) **Rearing house:** The rearing house should meet certain specification, as the silk worms are very sensitive to weather conditions like humidity and temperature. The rearing room should have proper ventilation optimum temperature and proper humidity. It should be ensured that dampness, stagnation of air, exposure to bright sunlight and strong wind should be avoided.

ii) **Rearing stand:** Rearing stands are made up of wood or bamboo and are portable. These are the frames at which rearing trays are kept. A rearing stand should be 2.5 m high, 1.5 m long and 1.0 m wide and should have 10 shelves with a space of 20 cm between the shelves. The trays are arranged on the shelves, and each stand can accommodate 10 rearing trays.

iii) **Ant well:** Ant wells are provided to stop ants from crawling on to trays, as ants are serious menace to silk worms. They are made of concrete or stone blocks 20 cm square and 7.5 cm high with a deep groove of 2.5 cm running all round the top. The legs of the rearing stands rest on the centre of well filled with water.

iv) **Rearing tray:** These are made of bamboo or wood so that they are light and easy to handle. These are either round or rectangular.

v) **Paraffin paper:** This is a thick craft paper coated with paraffin wax with a melting point of 55°C. It is used for rearing early stages of silk worms and prevents withering of the chopped leaves and also help to maintain proper humidity in the rearing bed.

vi) **Foam rubber strips:** Long foam rubber strips 2.5 cm wide and 2.5 cm thick dipped in water are kept around the silkworm rearing bed during first two instar stages to maintain optimum humidity. Newspaper strips may also be used as a substitute.

vii) Chopsticks: These are tapering bamboo rods (1cm in diameter) and meant for picking younger stages of larvae to ensure the hygienic handling.

viii) Feathers: Bird feathers preferably white and large are important items of silkworm rearing room. These are used for brushing newly hatched worms to prevent injuries.

ix) Chopping board and Knife: The chopping board is made up of soft wood it is used as a base for cutting leaves with knife to the suitable size required for feeding the worms in different instar stages.

x) Leaf chambers: These are used for storing harvested leaves. The sidewalls and bottom are made of wooden strips. The chamber is covered on all sides with a wet gunny cloth.

xi) Cleaning net: These are cotton or nylon nets of different mesh size to suit the size variations of different instars of the silk worm. These are used for cleaning the rearing beds, and at least two nets are required for each rearing tray.

xii) Mountages: These are used to support silkworm for spinning cocoons. These are made up of bamboo, usually 1.8 m long and 1.2 m wide. Over a mat base, tapes (woven out of bamboo and 5-6 cm wide) are fixed in the form of spirals leaving a gap of 5-6 cm. They are also called chandrikes. Other types of mountage such as centipede rope mountage, straw cocooning frames etc. are also used.

xiii) Hygrometers and Thermometers: These are used to record humidity and temperature of therearing room.

xiv) Feeding stands: These are small wooden stands (0.9 m height) used for holding the traysduring feeding and bed cleaning.

Other equipment like feeding basins, sprayer, and leaf baskets may also be required.

Rearing Practices:

Silkworms must be reared with utmost care since they are susceptible to diseases. Therefore, to prevent diseases, good sanitation methods and hygienic rearing techniques must be followed. The appliances and the rearing room should be thoroughly cleaned and disinfected with 2-4% formaldehyde solution. Room temperature should be maintained around 25^0 C.

a. Procurement of quality seeds:

The most important step in silkworm rearing is the procurement of quality seeds free from diseases. Seeds are obtained from grainages, which are the centers for production of disease free seeds of pure and hybrid races in large quantities. These centers purchase cocoons from the certified seed cocoon producers. These cocoons are placed in well ventilated rooms with proper temperature (23-25^0 C) and humidity (70-80 %), and emergence of moth is allowed. Grainage rooms may be kept dark, and light may be supplied suddenly on the expected day of emergence to bring uniform emergence. Emerging moths are sexed and used for breeding purposes to produce seed eggs. Three hours of mating secures maximum fertilized eggs. The females are then made to lay eggs on paper sheets or cardboard coated with a gummy substance. Egg sheets are disinfected with 2% formalin, and then washed with water to remove traces of formalin and then dried up in shades. The eggs are transported in the form of egg sheet. However, it is easy to transport loose eggs. To loosen the eggs, the sheets are soaked in water. The loose eggs are washed in salt solution of 1.06-1.10 specific gravity to separate out unfertilized eggs and dead eggs floating on surface. Prior to the final washing, the eggs are disinfected with 2% formalin solution. Eggs are dried, weighed to the required standard and packed in small flat boxes with muslin covers and dispatched to buyers.

b. Brushing :

The process of transferring the silkworm to rearing trays is called brushing. Suitable time for brushing is about 10.00 am. Eggs at the blue egg stage are kept in black boxes on the days prior to hatching. The next day they are exposed to diffused light so that the larvae hatch uniformly in response to photic stimuli. About 90% hatching can be obtained in one day by this method. In case of eggs prepared on egg cards, the cards with the newly hatched worms are placed in the rearing trays or boxes and tender mulberry leaves are chopped into pieces and sprinkled over egg cards. In case of loose eggs a net with small holes is spread over the box containing the hatched larvae and mulberry leaves cut into small pieces are scattered over the net. Worms start crawling over the leaves on thenet; the net with worms is transferred to rearing tray.

c. Preparation of feed bed and feeding :

After brushing, the bed is prepared by collecting the worms and the mulberry leaves together by using a feather. The bed is spread uniformly using chopsticks. The first feeding is given after two hours of brushing. Feed bed is a layer of chopped leaves spread on a tray or over a large area. The first and second instar larvae are commonly known as chawki worms. For chawki worms, paraffin paper sheet is spread on the rearing tray. Chopped mulberry leaves are sprinkled on the sheet and hatched larvae are brushed on to the leaves. A second paraffin paper sheet is spread over the first bed. In betweentwo sheets water soaked foam rubber strips are placed to maintain humidity.

The 4th and 5th instars are reared in wooden or bamboo trays by any of the three methods: viz., shelf- rearing, floor-rearing and shoot-rearing. In shelf rearing, the rearing trays are arranged one above the other in tiers on a rearing stand which can accommodate 10 -11 trays. This method provides enough space for rearing, but it is uneconomical as it requires large number of laborers to handle the trays. Chopped leaves are given as feed in this method. In floor rearing, fixed rearing sheets of 5-7x1-1.5m size are constructed out of wooden or bamboo strips in two tiers one meter apart. These sheets are used for rearing. Chopped leaves are given as feed. This method is economical than the first one because it does not involve much labour in handling of trays. Shoot-rearing is most economical of the three methods. The rearing sheet used is one meter wide and any length long in single tier and the larvae are offered fresh shoot or twigs bearing leaves. This method can be practiced both outdoors and indoors depending upon the weather. Each age of the silk worms could be conveniently divided into seven stages: First feeding stage, sparse eating stage, moderate eating stage, active eating stage, premoulting stage, last feeding stage, moulting stage. The larvae have good appetite at first feeding stage and comparatively little appetite at sparse and moderate eating stages. They eat voraciously during active stage to last feeding stage after which they stop feeding.

d. Bed Cleaning :

Periodical removal of left over leaves and worms' excreta may be undertaken and is referred to as bed cleaning. It is necessary for proper growth and proper hygiene. Four methods are adopted: conventional method, husk method, net method, and combined husk and net method.

e. Spacing :

Provision of adequate space is of great importance for vigorous growth of silkworms. As the worms grow in size, the density in the rearing bed increases and conditions of over-crowding are faced. Normally it is necessary to double or triple the space by the time of moult from one to other instar stage, with the result that from the first to third instar the rearing space increases eight fold. In 4th instar, it is necessary to increase the space by two to three times and in 5th instar again twice. Thus, the rearing space increases up to hundred folds from the time of brushing till the time of maturation ofworms.

f. Mounting

Transferring mature fifth instar larvae to mountages is called mounting. When larvae are fully mature, they become translucent, their body shrinks, and they stop feeding and start searching for suitable place to attach themselves for cocoon spinning and pupation. They are picked up and put on mountages. The worms attach themselves to the spirals of the mountages and start spinning the cocoon. By continuous movement of head, silk fluid is released in minute quantity which hardens to form a long continuous filament. The silkworm at first lays the foundation for the cocoon structure by weaving a preliminary web providing the necessary foot hold for the larva to spin the compact shell of cocoon. Owing to characteristic movements of the head, the silk filament is deposited in a series of short waves forming the figure of eight. This way layers are built and added to form the compact cocoon shell. After the compact shell of the cocoon is formed, the shrinking larva wraps itself and detaches from the shell and becomes pupa or chrysalis. The spinning completes within 2-3 days in multi-voltine varieties and 3-4 days in uni- and bivoltine.

g. Harvesting of Cocoons:

The larva undergoes metamorphosis inside the cocoon and becomes pupa. In early days, pupal skin is tender and ruptures easily. Thus, early harvest may result in injury of pupa, and this may damage the silk thread. Late harvest has a risk of threads being broken by the emerging moth. It is, therefore, crucial to harvest cocoons at proper time. Cocoons are harvested by hand. After harvesting the cocoons are sorted out. The good cocoons are cleaned by removing silk wool and faecal matter and are then marketed. The cocoons are sold by farmers to filature units through Cooperative or State Govt. Agencies. The cocoons are priced on the basis Rendita and reeling parameters. Rendita may be defined as number of kg of cocoon producing 1 kg of raw silk.

Post Cocoon Processing:

It includes all processes to obtain silk thread from cocoon.

a. Stifling

The process of killing pupa inside cocoon is termed as stifling. Good-sized cocoon 8-10 days old are selected for further processing. Stifling is done by subjecting cocoon to hot water, steam, dry heat, sunexposure or fumigation.

b. Reeling

The process of removing the threads from killed cocoon is called reeling. The cocoons are cooked first in hot water at 95-97o C for 10-15 minutes to soften the adhesion of silk threads among themselves, loosening of the threads to separate freely, and to facilitate the unbinding of silk threads. This process is called cooking. Cooking enables the sericin protein to get softened and make unwinding easy without breaks. The cocoons are then reeled in hot water with the help of a suitable machine. Four or five free ends of the threads of cocoon are passed through eyelets and guides to twist into one thread and wound round a large wheel. The twisting is done with the help of croissure. The silk is transferred finally to spools, and silk obtained on the spool is called the Raw Silk or Reeled Silk. The Raw silk is further boiled, stretched and purified by acid or by fermentation and is carefully washed again and again to bring the luster. Raw Silk or Reeled Silk is finished in the form of skein and book for trading. The waste outer layer or damaged cocoons and threads are separated, teased and then the filaments are spun. This is called Spun Silk

Diseases and Pests of Silkworms:

I. Diseases:

a. Pebrine:

Pebrine is also known as pepper disease or corpuscle disease. The disease is caused by a sporozoan, *Nosema bombycis* (family Nosematidae). The main source of infection is food contaminated with spores. Infection can be carried from one larva to another by the spores contained in faeces or liberated in other ways by the moths carrying infection. Pebrinized eggs easily get detached from the egg cards. They may be laid in lumps. The eggs may die before hatching. The larva shows black spots. They may become sluggish and dull, and the cuticle gets wrinkled. Pupa may show dark spots. Moths emerging from pebrinized cocoons have deformed wings and distorted antennae. The egg laying capacityof the moth becomes poor

b. Flacherie:

Flacherie is a common term to denote bacterial and viral diseases. It has been classified into following types:-

i) Bacterial diseases of digestive organs: Due to the poor supply of quality mulberry leaves, the digestive physiology of the silkworm is disturbed, and multiplication of bacteria occurs in the gastric cavity. Bacteria like Streptococci, Coli, etc. have been found associated with this disease. Symptoms, like diarrhoea, vomiting, shrinkage of larval body may be seen.

ii) Septicaemia: Penetration and multiplication of certain kinds of bacteria in haemolymph cause septicaemia. The principal pathogenic bacteria are large and small Bacilli, Streptococci, and Staphylococci etc. Symptoms like diarrhoea, vomiting, shrinkage of larval body may be seen. Appearance of foul odour is also a common symptom.

iii) Sotto disease: It is caused by toxin of *Bacillus thuringensis*. The larvae become unconscious, soft, and darkish and rot off.

iv) Infectious Flacherie: It is caused by a virus called Morator Virus which does not form polyhedra in the body of silkworm larvae. The infection occurs mainly through oral cavity. The virus multiplies in the midgut and is released into the gastric juice and is excreted in faeces.

v) Cytoplasmic polyhedrosis: It is caused by a virus called Smithia which form Polyhedra are formed in the cytoplasm of the cylindrical cells of the midgut. The larva loses appetite. The head may become disproportionately large. Infection occurs through the oral cavity.

c. Grasserie:

The disease is also known as Jaundice or Nuclear Polyhedrosis It is caused by a virus called Borrelina, which form polyhedra in the nuclei of the cells of fatty tissues , dermal tissues, muscles, tracheal membrane, basement membrane, epithelial cells of midgut and blood corpuscles. The infected larvae lose appetite, become inactive, membranes become swollen, skin becomes tender and pus leaks out from skin. The larvae finally die.

Muscardine or Calcino: It is of 3 types

i) White Muscardine: It is caused by the fungus, *Beuveriabassiana*. The larva loses appetite, body loses elasticity and they cease to move and finally die.

ii) Green Muscardine: It is caused by *Metarrhiziumanisopliae*. The larva loses appetite, appears yellowish, becomes feeble and dies.

iii) Yellow Muscardine: It is caused by *Isaria farinosa*. Many small black specks appear on the skin. Larvae lose appetite and dies.

II. Pests

i. *Tricholyga bombycis*: It is a dipteran fly of the family tachinidae, commonly known as Uzi fly. It is a serious pest of silkworm larvae and pupae. It parasitizes Mulberry and Tasar silkworm.

ii. Dermestid beetles: These insects belong to the order Coleoptera, family dermestidae. This family contains many genera and a large number of destructive species. Some of them are: *Dermestes cadverinus, D. valpinus, D. vorax, D. frishchi,* and *Trogoderma versicolor*. The larvae bore inside the cocoon and eat the pupa. These pests cause great damage and economical loss, as the damaged cocoons cannot be reeled.

iii. Mites: *Pediculoides ventricosus* (order Acarina, class Arachnida) damage the larvae. The toxic substance produced by the mite kills the silkworms. In addition, ants, lizards, birds, rats and squirrel also cause considerable damage to silkworm larvae as well as the cocoons.

Silk and Its Use:

- ### Properties of the silk:

Silk contains 70-75% fibroin and 25-30% sericin protein. The biochemical composition of fibroin can be represented by the formula $C15H23N5O6$. It has the characteristic appearance of pure silk with pearly lustre. It is insoluble in water, ether or alcohol, but dissolves in concentrated alkaline solutions, mineral acids, and glacial acetic acid and in ammoniacal solution of oxides of copper. Sericin, a gummy covering of the fiber is a gelatinous body which dissolves readily in warm soapy solutions and in hot water, which on cooling forms a jelly with even as little as 1% of the substance. It is precipitated as a white powder from hot solutions by alcohol. Its chemical formula is $C_{15}H_{25}N_5O_8$. It can be dyed before or after it has been woven into a cloth. The weight in gram of 900m long silk filaments is called a denier which represents size of silk filament.

- ### Silk has following peculiar properties:

1. Natural colour of Mulberry silk is white , yellow or yellowish green; that of Tasar

brown; of Muga, light brown or golden; and of Eri, brick red or creamy white or light brown.

2. Silk has all desirable qualities of textile fibres, viz. strength, elasticity, softness, coolness, and affinity to dyes. The silk fibre is exceptionally strong having a breaking strength of 65,000-lbs/sq. inch.

3. Silk fibre can elongate 20% of original length before breaking.

4. Density is 1.3-1.37g/cm3 .

5. Natural silk is hygroscopic and gains moisture up to 11%.

6. Silk is poor conductor of heat and electricity. However, under friction, it produces static electricity.Silk is sensitive to light and UV- rays.

7. Silk fibre can be heated to higher temperature without damage. It becomes pale yellow at 110o C in15 minutes and disintegrates at 165o C.

8. On burning it produces a deadly hydrocyanic gas.

- ## Use of silk:

Silk is used in the manufacture of following articles:

a. Garments in various weaves like plain, crepe, georgette and velvet.

b. Knitted goods such as vests, gloves, socks, stockings.

c. Silk is dyed and printed to prepare ornamented fabrics for saries, ghagras, lehengas.

d. Jackets, shawls and wrappers.

e. Caps, handkerchiefs, scarves, dhotis, turbans.

f. Quilts, bedcovers, cushions, table-cloths and curtains generally from Erisilk or spun silk.Parachutes and parachute cords.

g. Fishing lines.

h. Sieve for flour mills.

i. Insulation coil for electric and telephone wire.

j. Tyres of racing cars.

k. Artillery gunpowder.

l. Surgical sutures.

❖ Indian Scenario:

Silk is Nature’s gift to mankind and a commercial fibre of animal origin other than wool. Being an eco-friendly, biodegradable and self-sustaining material; silk has assumed special relevance in present age. Promotion of sericulture can help in ecosystem development as well as high economic returns. Sericulture is practiced in India and India is the 5th largest producer of silk in the World. It has been identified as employment oriented industry. All the sections of sericulture industry, viz. mulberry cultivation, silkworm seed production, silkworm rearing, reeling and weaving of silk and collection of byproducts and its processing provide a large scale employment, thereby a source of livelihood for the rural and tribal people. Sericulture industry is rated as the second largest employer in India.

Owing to this peculiar nature, the Indian planners have identified sericulture as one of the best suited occupations for ideal growth and development of rural India. Mulberry sericulture has been traditional occupation in Karnataka, Tamil Nadu, A.P. and Kashmir; Tasar one, in M.P., Chota Nagpur Division and Orissa; Muga one, in Assam, Nagaland, Tripura and Eri one in Assam and West Bengal. North- eastern part of India is the only region in the world where all four varieties of silk are produced. Central and State level Government Silk Departments are actively engaged in addressing the objective of promotion of sericulture in traditional as well as non-traditional regions. With the launching of massive developmental schemes, it is expected to gain an accelerated tempo of sericultural activities in the country, paving way for doubling the employment opportunities in phased manner, and thereby, it may set to bring a soothing touch to the burning problem of acute unemployment in rural India and thus can check the rural migration to urban areas to a certain extent. Sericulture is an agro-based cottage industry involving interdependent rural, semi-urban and urban-based activities in which estimated participation of women is about 60%. Thus, in contrast to any other agro-based profession the role of women in sericulture industry is dominating which will be helpful for improving the status of women in family enterprises. In the light of women welfare through Sericulture industry, the Central Silk Board, a statutory organization, under the Ministry of Textiles, Government of India has established a special component of assistance to Women and NGO’s’ into the National Sericulture Project.

There are four major research centres for Sericulture in India:

1. Central Sericulture Research and Training Institute, Behrampur (Orissa).
2. Central Sericulture Research and Training Institute, Mysore (Karnataka).
3. Central Tasar Research and Training Institute, Ranchi (Jharkhand).
4. Central Silk Technological Research Institute, Bangalore (Karnataka).

Probable questions:

1. Write down scientific names of Mulberry, Tasar , Muga and Eri silkmoth.
2. What is Voltinism? Name one of each type.
3. Describe life cycle of Bombyx mori with suitable diagram.
4. How mounting ids done in sericulture?
5. How cocoons are harvested?
6. Write down post cocoon processing.
7. Describe any two diseases of silkworm.
8. What is the present scenario of sericulture in India.
9. Describe the properties of silk.
10. What are the uses of silk?

Suggested Readings:

1. The Insects by Chapman
2. Modern Entomology by D.B. Thembare
3. Economic Zoology by Shukla and Upadhyay
4. The Insects by Gullan and Carnston
5. Introduction to Economic Zoology by Sarkar, Kundu and Chaki.
6. A textbook of Economic Zoology by Aminul Islam

UNIT VII

Parasitic insects and Acarines: General remarks on *Phlebotomous* and *Glossina* in relation to morphology, habit, habitat, life cycle and disease caused by them, mode of transmission

Objectives:

In this unit we will know about morphology, habit, habitat, life-cycle of some parasitic insects like *Phlebotomous* and *Glossina*. You will also know about disease caused by them and mode of transmission.

A. *Phlebotomous sp.* (Common Name : Sand Fly)

Introduction:

Sand flies are of great importance as the transmitters of various kinds of leishmaniasis, of a filtrable virus disease called three-day fever or more commonly sand-fly or Papatasi fever and of Oroya fever. These are blood sucking flies and they belong to the genus *Phlebotomous*. These are small, moth like flies, rarely over 5 mm long. Their bodies and wings are black and hairy.

The legs are long and the wings are held roof-like over the abdomen during rest. The antennae are long, consisting of 16 segments which often have a beaded appearance and they are thickly covered with hairs. They live in moist dark place and lay eggs in sandy soil so they are called sandflies. Several species of Sandflies are recognised. These are *P. papatasii, P. minutus, P. argentipes, P. orientalis, P. sergenti, P. nogouchi* etc. Among these species—*P. papatasii* is found in North India, *P. argentipes* in Assam and West Bengal, and *P. minutus* in other states of India.

Systematic Position:

Kingdom: Animalia
Phylum: Arthropoda
Class: Insecta
Order: Diptera
Family: Psychodidae
Subfamily:Phlebotominae
Genus: *Phlebotomous*

Habit:

Both male and female sand flies feed on plant juices and sugary secretions. Females also blood feed to produce eggs. Sand flies use their mouthparts to probe exposed skin, leading to the formation of a pool of blood from which they feed. Sand fly saliva contains pharmacologically active components that aid in the feeding process. Feeding activity is influenced by temperature, humidity and air movement (sand flies are weak fliers so even light wind can inhibit flight and reduce biting). Most species feed at dusk and during the night, when temperature falls and humidity rises. The majority of species feed outdoors, although daytime biting can occur indoors in darkened rooms or among shaded vegetation/trees, especially if disturbed by human activity.

Habitat:

Phlebotomous spp. occurs predominantly in warm, humid and tropical climates, usually in savannah and semi-desert vegetation habitats, although a few species occur in temperate zones. They are able to colonise rural, peri-urban and urban areas. Sand flies require a humid microclimate in order for their eggs to develop and larvae need a cool, moist habitat with decaying debris. Adult sand flies often inhabit rock crevices, caves, and rodent burrows, and in peri-domestic settings. They rest in cool, dark and humid corners of animal shelters or human dwellings. Both rodent burrows and peri-domestic areas provide ready access to blood meals in addition to shelter from the elements.

Host preference:

Female sand flies feed on a wide variety of vertebrate hosts, including humans, livestock, dogs, urban and wild rodents, reptiles, amphibians, and birds. Each species of sand fly may have its own specific host preferences, although host availability is an important factor in determining blood feeding behaviour. It is likely that many species of sand fly are opportunistic and feed on animals to which they have easiest access, as the same species collected from different biotopes often display different feeding patterns. A study of sand fly species from farms and kennels in Italy found that *Phlebotomous papatasi, Phlebotomous perniciosus and Phlebotomous perfiliewi* fed primarily on the host species (livestock and humans) that were present at the collection site. If many different animals were present, both *Phlebotomous perfiliewi* and *Phlebotomous perniciosus* were found to feed on all of them, suggesting that choice of host is influenced by the presence and proportion of each host. As a result, it is likely that in urban and peri-urban settings humans and domestic dogs are the main targets for sand flies.

Morphology:

Larva: Larvae are caterpillar-shaped with head capsules and small leaf-like antennae. Distinctive caudal setae can help identify the larvae as sand flies, but larvae are rarely used in taxonomy because very few are ever collected in nature. There are four larval instars ranging in size from0.55 mm long in the 1st to about 3.2 mm long in the 4th. The 1st instar larvae usually have two long caudal setae, but the 2nd instar larvae have 4 caudal setae upon moulting.

Pupae: Pupae resemble a small butterfly chrysalis except that the 4th-stage larval exuvium (cast off exoskeleton) is attached at one end. The exuvium acts as glue which is attached to a solid substrate and holds the pupa upright.

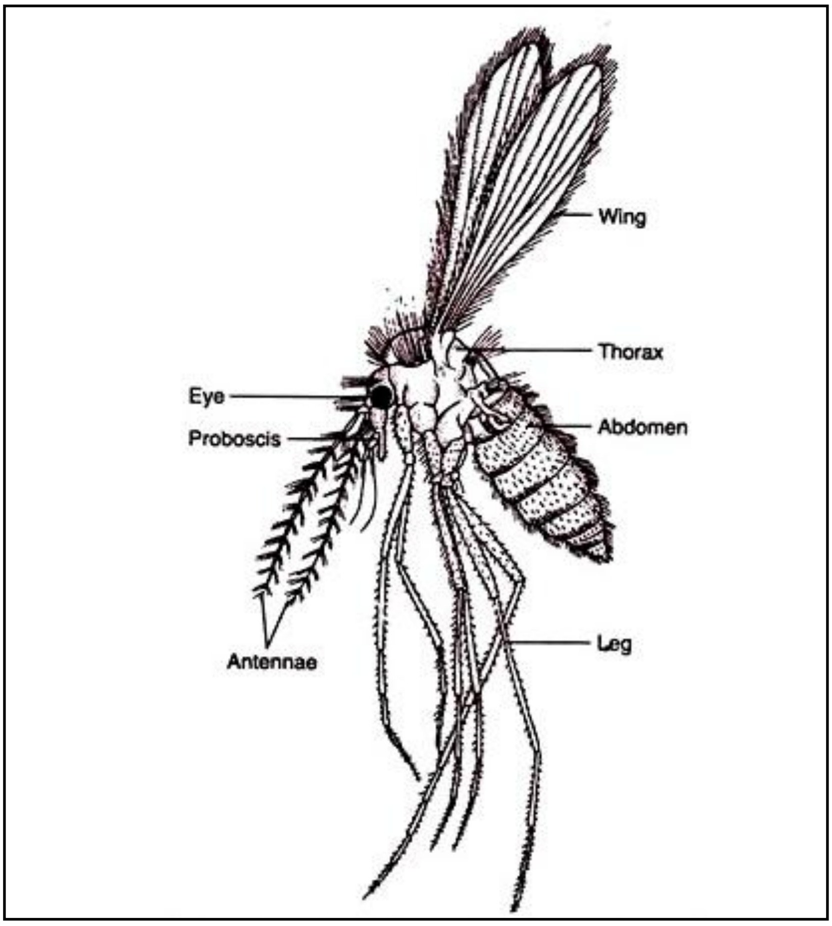
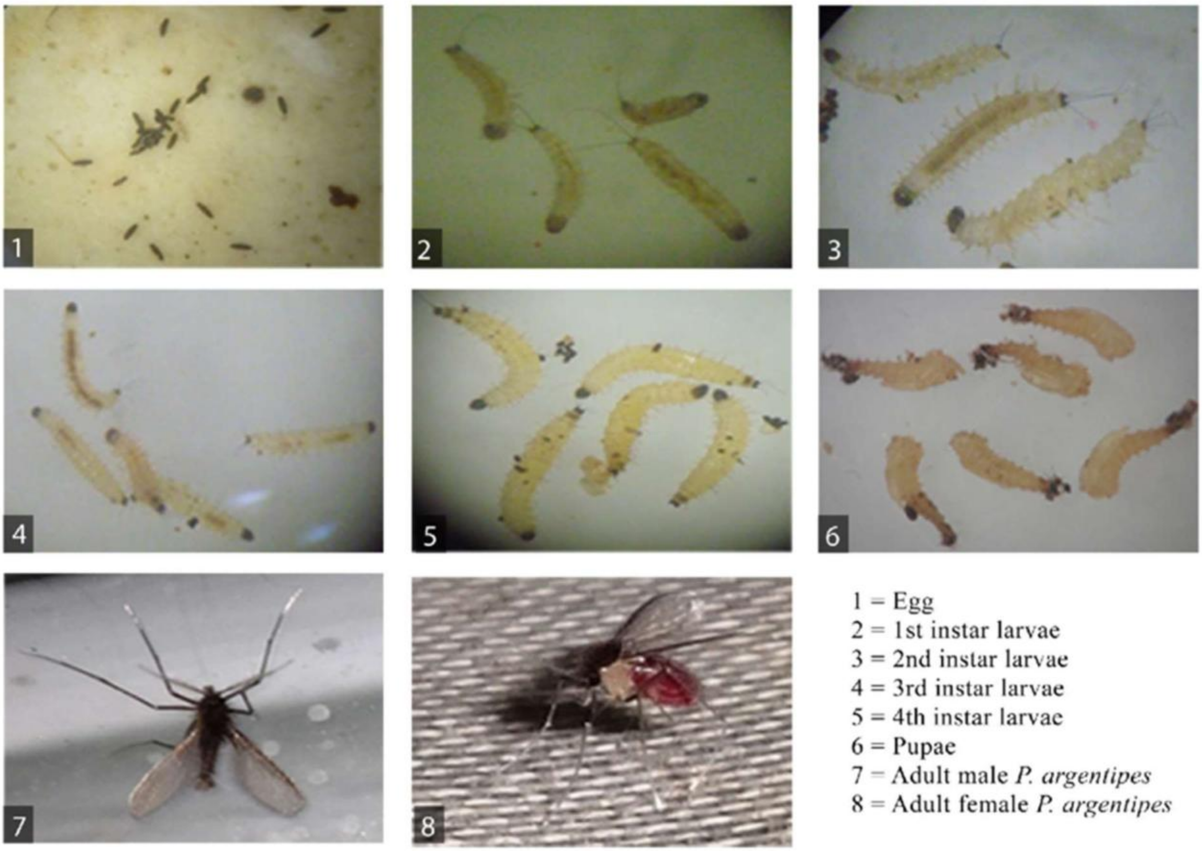


Fig: Adult structure of *Phlebotomus argentipes*

Adults: Adult sand flies are about one-third the length of a small mosquito, usually less than 3.5mm in length. They are covered with dense hairs and hold their wings in a characteristic "V" shape over their backs when at rest. The wing veins are parallel to each other and have numerous small "hairs". The eyes are large and dark. The antennae are long and filiform, with 16 segments. Mouth parts are short, dagger-shaped and oriented downward. The thorax is distinctively humped, pushing the head below the upper surface of the thorax. The legs are very long and delicate. Both female and male sand fly adults obtain carbohydrate nutrition from plant juices; however, most females also require at least one blood meal in order to complete development of egg batches. Some are autogenous (able to produce viable eggs without a blood meal). Acquisition of a disease agent is therefore incidental to blood meals.



Life cycle of sand fly:

Reproduction and oviposition:

Adult sand flies mate soon after emergence; males locate females at resting sites or on vertebrate hosts, with the aid of pheromones. Female sand flies usually lay 30-70 eggs during a single gonotrophic cycle, which are deposited in cracks and holes in the ground or in buildings, animal burrows and among tree roots. The eggs require a microhabitat with high humidity in order to survive, but are not laid in water. Generally, one blood meal results in the production of a single batch of eggs.

The life cycle of the phlebotomine sand fly (*P. argentipes*) is divided into four stages.

Eggs:

The female sand fly (*P. argentipes*) requires blood meals to lay an average of 32.66 eggs. The time lag between the engorgement to oviposition is not less than six days. The eggs are elongated oval- shaped, pale at first and darkening following exposure to air with a single black 'eye spot'. Within one to two weeks of oviposition (unless weather conditions become too cold), eggs hatch. The average incubation period for hatching lasts three–six days, with a mean of 3.96 days at a temperature of 25 ± 2 °C; the hatching rate under these conditions is 67.8%. If weather conditions become too cold, the eggs enter diapause during which they do not develop further. The development process restarts once temperature reaches sufficient levels (i.e. around 25 °C).

Larvae:

Originating from aquatic larvae, the larval stages have adapted to live in moist soil, where development takes on average 15.5 days (range 11–29 days). The larvae emerge through a J-shaped fissure and are legless, whitish, and with a dark head capsule. This usually occurs when humidity levels approach 100%, leading to soil moisture of ~12%.

The larvae possess a cylindrical, elongated, and segmented body. The first instar can be distinguished by the presence of two caudal bristles, while all subsequent instars have four caudal bristles. All larvae feed on dead organic matter and are often found in cracks of walls or rocks, animal burrows, caves, or below decaying leaves. The larvae cannot exist without water in the fluid form, but water may be bound by capillary action. The larvae, particularly younger instars, absorb water with their food and through the skin. In the urban areas, the larvae are found in the floors, loose bricks, and rat holes. Fourth instars can be distinguished by the presence of a prominent sclerite on the dorsum of the penultimate segment.

Pupae:

Following the larval stage, the developing sand fly (*P. argentipes*) enters the pupal stage on floating debris or near the water's edge. The pupae are golden brown and are affixed to the surface of the substrate on which they develop. Shortly before emergence, the wings and eyes turn black. The developmental period for pupal stage ranges from 6 to 10 days, with a mean of 7.65. Adults emerge just before dawn.

Adults:

Male sand flies emerge about 24 h before females, allowing time to rotate their external genitalia 180° to the correct position for mating. Although there have been no field studies of sand fly development time, the time from oviposition to adult emergence at ambient temperatures is around four–six weeks. Adult emergence takes place at a temperature of 25 ± 2°C. During winter months (December– February), the development period decreases with the duration of each life cycle, from 25 to 40 days per generation.

Only the adult female sand fly (*P. argentipes*) sucks vertebrate host's blood, a requirement for egg production. Both males and females feed on plant sugars. The adults of *P. argentipes* are 2–3 mm long and because sand flies are so small, they have nicknames such as 'no see ums' and 'punkies'. They cannot fly hence display a characteristic 'hopping movement' and consequently cannot move more than 106 meters from their breeding place, though they have been recorded from canopy of trees. Under favorable conditions, development from egg to adult takes approximately one month.

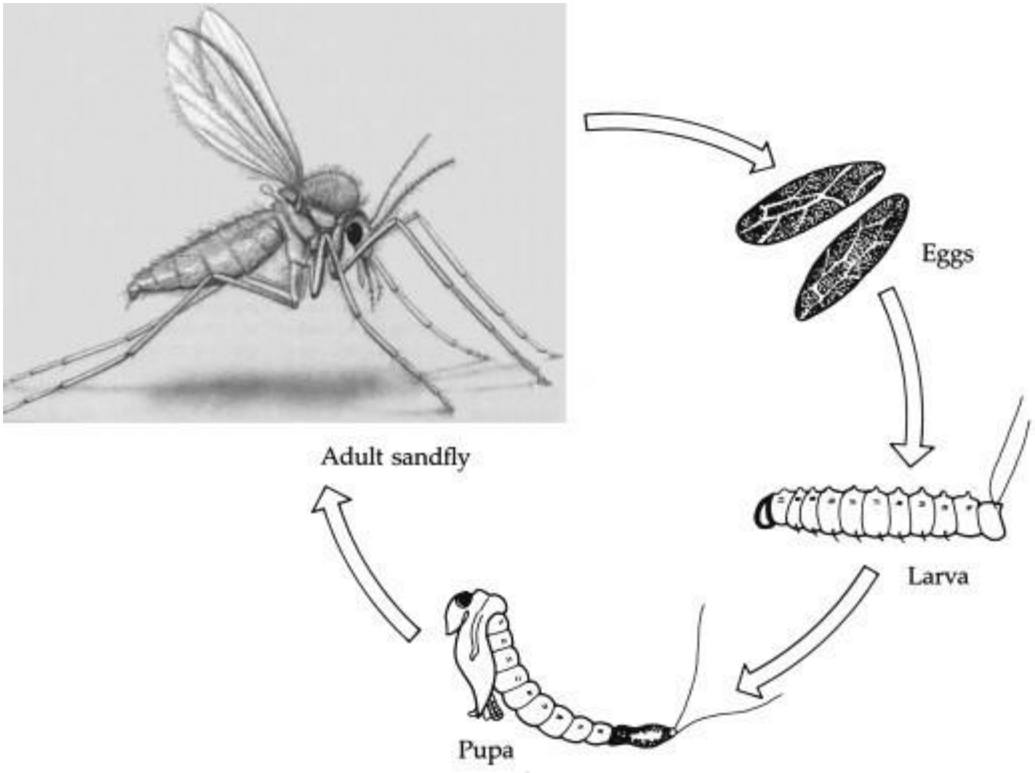


Figure: Life Cycle of *Phlebotomous argentipes*

Method of Transmission:

Sand flies act as the transmitters of various types of diseases, such as Leishmaniasis, Sand-fly fever, Oroya fever, Carrions disease etc.

Leishmaniasis:

Kala-azar, also known as Dum-dum fever, is a serious oriental disease of man. It is found in India, China, Mediterranean countries and parts of Africa and South America. Its causative agent is a pathogenic flagellate, known as *Leishmania donovani* which is transmitted by the bite of small blood sucking sandflies called *Phlebotomus argentipes*. The transmission of this pathogen (*L. donovani*) from man to man is carried out by a certain species of Sand-fly.

The species concerned are as follows:

Indian vector:

P. argentipes; Chinese vectors: *P. chinensis*, and *P. sergenti*; Mediterranean vectors: *P. perniciosus* (Italy and Sicily); Turkestan vector: *P. caucasicus*; Tropical American vector: *P. intermedius*; Sudanese vector: *P. orientalis*; East African vector: *P. martini*, Russian vector: *P. arpaklensis*. The symptoms of kala-azar include swelling, high fever, and enlargement of spleen and liver. It is followed by general weakness, emaciation, anaemia and a peculiar darkening of the skin.

Sand-fly fever:

It is a mild virus disease and in many respects this Sand-fly fever resembles dengue. It comes on suddenly with fever, headache, pain in the eyes, stiffness of neck and back and rheumatic pain and is often followed by a prolonged period of malaise and depression.

It was experimentally shown by Doerr (1908) to be transmitted by *P. papatasii*. The insects become infective about 6 or 7 days after feeding on a patient in the first or second day of the fever. Since Sandflies are so short lived and frequently suck blood only once and since the disease appears as soon as the adults emerge in May in Mediterranean area, evidently being passed the winter in the larvae, transovarial transmission had long been suspected.

Since only man is known to be susceptible, transovarial transmission seems necessary for survival of the virus from one season to another. Thus *P. papatasii* is the only known transmitter throughout the definite range of the disease.

Oroya fever or Carrions disease:

It is an acute febrile disease caused by a very minute organism, *Bartonella bacilliformis*. *P. nogouchi* is a Sand-fly which is found in South America. This Sand-fly acts as a vector of this pathogen which is responsible for Carrions disease.

Both the sexes of this Sand-fly suck blood of man and domesticated animals. The acute stage of the disease is characterized by high fever, severe anaemia, aches and albuminuria and is often fatal. In chronic cases it is followed by an eruption of nodules called verruga peruviana.

Pathogenicity and role of *Phlebotomous* as vector:

In the Old World, *Phlebotomous* sand flies are primarily responsible for the transmission of leishmaniasis, an important parasitic disease, while transmission in the New World, and are generally via sand flies of the genus *Lutzomyia*. The protozoan parasite itself is a species of the genus *Leishmania*. Leishmaniasis normally finds a mammalian reservoir in rodents and other small animals such as canids (canine leishmaniasis) and hyraxes. The female sand fly carries the *Leishmania* protozoa from infected animals after feeding, thus transmitting the disease, while the male feeds on plant nectar.

The parasite *Leishmania donovani* is the main causative agent of visceral leishmaniasis

(VL) in India, Nepal, and Bangladesh, where it is transmitted by the sand flies of the species *Phlebotomous argentipes*. This species of sand flies was on the brink of elimination in India during the 1960s following the widespread use of DDT for malaria control. However, there was resurgence in their population a decade later.

Phlebotomous species are also vectors for bartonellosis, verruga peruana, and pappataci fever, an arboviral disease caused by sandfly fever viruses such as the Naples and Sicilian strains of the genus *Phlebovirus* (family *Bunyaviridae*), which also includes the closely related Toscana virus. In Egypt, two species of medical importance are *Phlebotomous papatasii* and *P. langerni*. These flies are short-lived. Females are blood suckers at night; males feed on plant juices. Adults are poor fliers; they usually hop for short distances.

B. *Glossina sp.* (Common name – Tsetse fly)

Introduction:

Tsetse sometimes spelled tzetze and also known as tik-tik flies, are large biting flies that inhabit much of tropical Africa. Tsetse flies include all the species in the genus *Glossina*, which are placed in their own family, Glossinidae. The tsetse is obligate parasites that live by feeding on the blood of vertebrate animals. Tsetse has been extensively studied because of their role in transmitting disease. They have a prominent economic impact in sub-Saharan Africa as the biological vectors of trypanosomes, which cause human sleeping sickness and animal trypanosomiasis. Tsetse are multivoltine and long-lived, typically producing about four broods per year, and up to 31 broods over their lifespans.

Tsetse can be distinguished from other large flies by two easily observed features. Tsetse folds their wings completely when they are resting so that one wing rests directly on top of the other over their abdomens. Tsetse also has a long proboscis, which extends directly forward and is attached by a distinct bulb to the bottom of their heads.

Tsetse were absent from much of southern and eastern Africa until colonial times. The accidental introduction of rinderpest in 1887 killed most of the cattle in these parts of Africa and the resulting famine removed much of the human population. Thorny bush ideal for tsetse quickly grew up where there had been pasture, and was repopulated by wild mammals. Tsetse and sleeping sickness soon colonised the whole region, effectively excluding the reintroduction of farming and animal husbandry. Sleeping sickness has been described by some conservationists as "the best game warden in Africa".

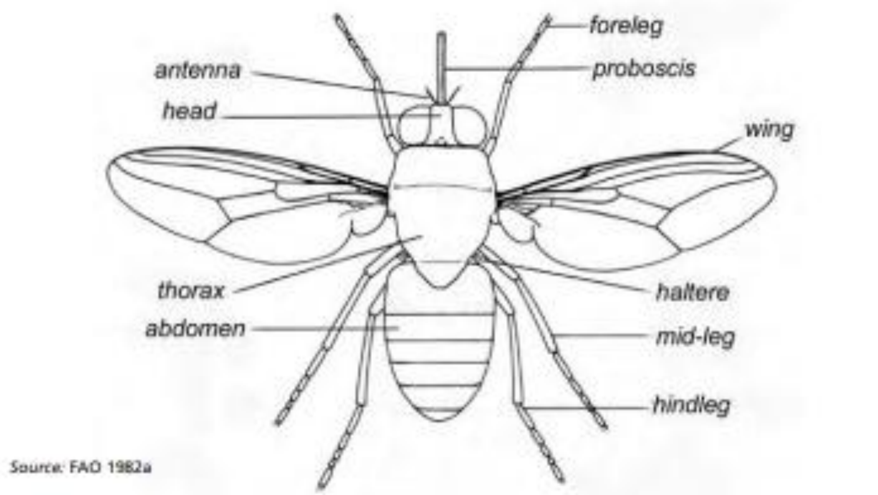
Morphology

Tsetse flies can be seen as independent individuals in two forms: as third-instar larvae, and as adults. Tsetse first becomes separate from their mothers during the third larval instar, during which they have the typical appearance of maggots. However, this life stage is short, lasting at most a few hours, and is almost never observed outside of the laboratory.

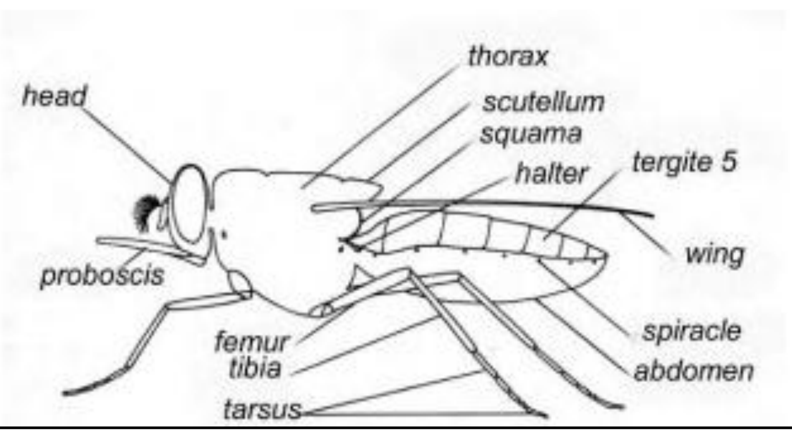
Tsetse next develops a hard external case, the puparium, and become pupae—small, hard-shelled, oblongs with two distinctive, small, dark lobes at the tail (breathing) end. Tsetse pupae are under 1 cm long. Within the puparial shell, tsetse complete the last two larval instars and the pupal stage.

At the end of the pupal stage, tsetse emerge as adult flies. The adults are relatively large flies, with lengths of 0.5-1.5 cm, and have a recognizable shape or bauplan which makes them easy to distinguish from other flies. Tsetse has large heads, distinctly separated eyes, and unusual antennae. The thorax is quite large, while the abdomen is wide rather than elongated and shorter than the wings.

Diagram of a tsetse fly indicating the parts of the external anatomy



Diagrammatic side view of a tsetse fly



Four characteristics definitively separate adult tsetse from other kinds of flies:

a. Proboscis: Tsetse has a distinct proboscis, a long thin structure attached to the bottom of the head andpointing forward.

b. Folded wings: When at rest, tsetse fold their wings completely one on top of the other.

c. Hatchet cell: The discal medial ("middle") cell of the wing has a characteristic hatchet shape resemblinga meat cleaver or a hatchet.

d. Branched arista hairs: The antennae have arista with hairs which are themselves branched.

Life Cycle:

Tsetse has an unusual lifecycle which may be due to the richness of their food source. A female fertilizes only one egg at a time and retains each egg within her uterus to have the offspring develop internally during the first three larval stages, a method called **adenotrophic viviparity.** During this time, the female feeds the developing offspring with a milky substance secreted by a modified gland in the uterus. In the third larval stage, the tsetse larva leaves the uterus and begins its independent life. The newly independent tsetse larva crawls into the ground, and develops a hard outer shell called the puparial case, in which it completes its morphological transformation into an adult fly.

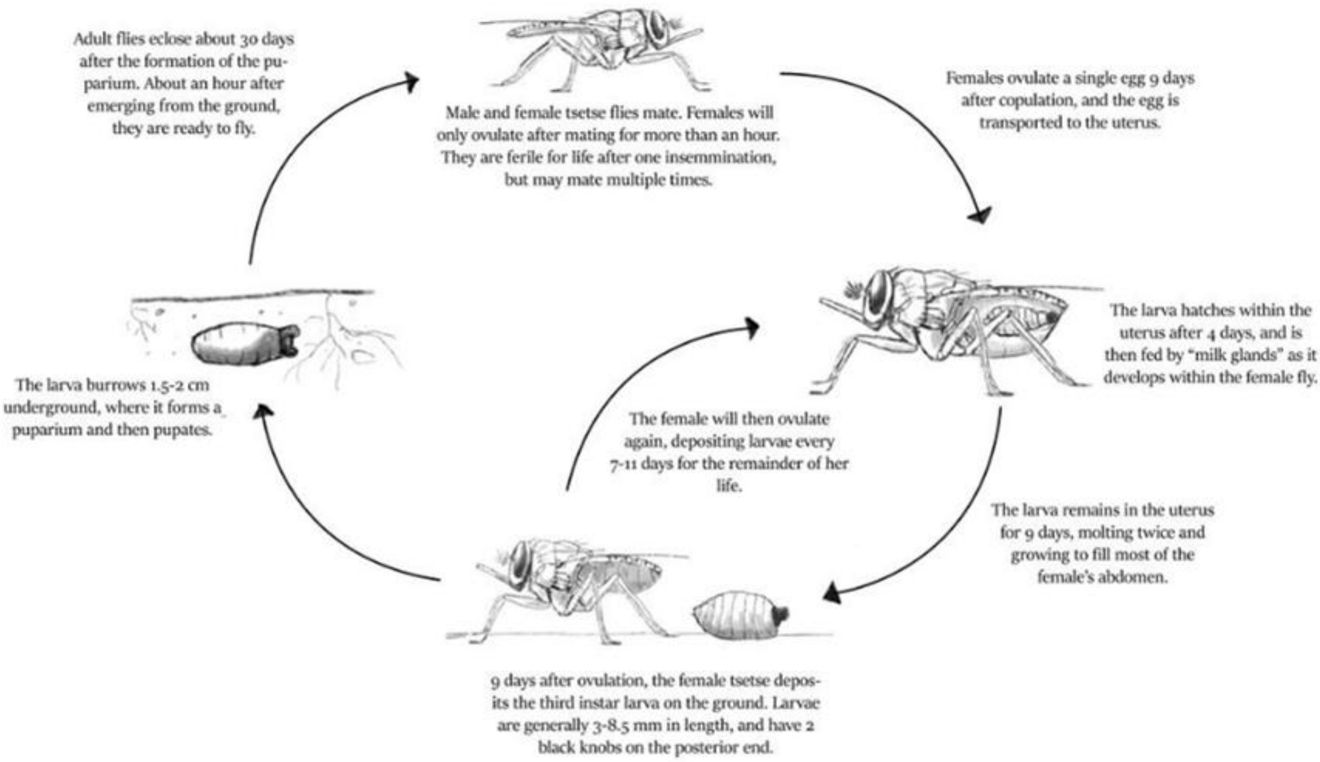


Figure: Life cycle of *Glossinia* sp

This life stage has a variable duration, generally 20 to 30 days, and the larva must rely on stored resources during this time. The importance of the richness of blood to this development can be seen, since all tsetse development before it emerges from the puparial case as a full adult occurs without feeding, based only on nutritional resources provided by the female parent. The female must get enough energy for her needs, for the needs of her developing offspring, and for the stored resources which her offspring will require until it emerges as an adult.

Technically, these insects undergo the standard development process of insects, which consists of oocyte formation, ovulation, fertilization, development of the egg, three larval stages, a pupal stage,and the emergence and maturation of the adult.

Role of *Glossina* in disease transmission:

Tsetse are biological vectors of trypanosomes, meaning that in the process of feeding, they acquire and then transmit small, single-celled trypanosomes from infected vertebrate hosts to uninfected animals. Some tsetse-transmitted trypanosome species cause trypanosomiasis, an infectious disease. In humans, tsetse transmitted trypanosomiasis is called sleeping sickness. In animals, tsetse-vectored trypanosomiasis includes *nagana*, *souma*, and *surra* according to the animal infected and the trypanosome species involved. The usage is not strict and while *nagana* generally refers to the disease in cattle and horses it is commonly used for any of animal trypanosomiasis.

Trypanosomes are animal parasites, specifically protozoans of the genus *Trypanosoma*. These organisms are about the size of red blood cells. Different species of trypanosomes infect different hosts. They range widely in their effects on the vertebrate hosts. Some species, such as *T. theileri*, do not seem to cause any health problems except perhaps in animals that are already sick.

Some strains are much more virulent. Infected flies have an altered salivary composition which lowers feeding efficiency and consequently increases the feeding time, promoting trypanosome transmission to the vertebrate host. These trypanosomes are highly evolved and have developed a lifecycle that requires periods in both the vertebrate and tsetse hosts.

Tsetse transmits trypanosomes in two ways, mechanical and biological transmission.

- **Mechanical transmission** involves the direct transmission of the same individual trypanosomes taken from an infected host into an uninfected host. The name 'mechanical' reflects the similarity of this mode of transmission to mechanical injection with a syringe. Mechanical transmission requires the tsetse to feed on an infected host and acquire trypanosomes in the blood meal, and then, within a relatively short period, to feed on an uninfected host and regurgitate some of the infected blood from the first blood meal into the tissue of the uninfected animal. This type of transmission occurs most frequently when tsetse are interrupted during a blood meal and attempt to satiate themselves with another meal. Other flies, such as horse-flies, can also cause mechanical transmission of trypanosomes.

- **Biological transmission** requires a period of incubation of the trypanosomes within the tsetse host. The term 'biological' is used because trypanosomes must reproduce through several generations inside the tsetse host during the period of incubation, which requires extreme adaptation of the trypanosomes to their tsetse host. In this mode of transmission, trypanosomes reproduce through several generations, changing in morphology at certain periods. This mode of transmission also includes the sexual phase of the trypanosomes. Tsetse is believed to be more likely to become infected by trypanosomes during their first few blood meals. Tsetse infected by trypanosomes is thought to remain infected for the remainder of their lives. Because of the adaptations required for biological transmission, trypanosomes transmitted biologically by tsetse cannot be transmitted in this manner by other insects.

The relative importance of these two modes of transmission for the propagation of tsetse-vectored trypanosomiases is not yet well understood. However, since the sexual phase of the trypanosome lifecycle occurs within the tsetse host, biological transmission is a required step in the lifecycle of the tsetse-vectored trypanosomes.

The cycle of biological transmission of trypanosomiasis involves two phases, one inside the tsetse host and the other inside the vertebrate host. Trypanosomes are not passed between a pregnant tsetse and her offspring, so all newly emerged tsetse adults are free of infection. An uninfected fly that feeds on an infected vertebrate animal may acquire trypanosomes in its proboscis or gut. These trypanosomes, depending on the species, may remain in place, move to a different part of the digestive tract, or migrate through the tsetse body into the salivary glands. When an infected tsetse bites a susceptible host, the fly may regurgitate part of a previous blood meal that contains trypanosomes, or may inject trypanosomes in its saliva. Inoculation must contain a minimum of 300 to 450 individual trypanosomes to be successful, and may contain up to 40,000 cells.

The trypanosomes are injected into vertebrate muscle tissue but make their way, first into the lymphatic system, then into the bloodstream, and eventually into the brain. The disease causes the swelling of the lymph glands, emaciation of the body, and eventually leads to death. Uninfected tsetse may bite the infected animal prior to its death and acquire the disease, thereby closing the transmission cycle.

Disease hosts and vectors:

The tsetse-vectored trypanosomiasis affects various vertebrate species including humans, antelopes, bovine cattle, camels, horses, sheep, goats, and pigs. These diseases are caused by several different trypanosome species that may also survive in wild animals such as crocodiles and monitor lizards. The diseases have different distributions across the African continent, so are transmitted by different species.

In humans:

Human African trypanosomiasis, also called sleeping sickness, is caused by trypanosomes of the species *Trypanosoma brucei*. This disease is invariably fatal unless treated but can almost always be cured with current medicines, if the disease is diagnosed early enough.

Sleeping sickness begins with a tsetse bite leading to an inoculation in the subcutaneous tissue. The infection moves into the lymphatic system, leading to a characteristic swelling of the lymph glands called *Winterbottom's sign*.[23] The infection progresses into the blood stream and eventually crosses into the central nervous system and invades the brain leading to extreme lethargy and eventually to death.

The species *Trypanosoma brucei*, which causes the disease, has often been subdivided into three subspecies that were identified based either on the vertebrate hosts which the strain could infect or on the virulence of the disease in humans. The trypanosomes infectious to animals and not to humans were named *Trypanosoma brucei brucei*. Strains that infected humans were divided into two subspecies based on their different virulences: *Trypanosoma brucei gambiense* was thought to have a slower onset and *Trypanosoma brucei rhodesiense* refers to strains with a more rapid, virulent onset. This characterization has always been problematic but was the best that could be done given the knowledge of the time and the tools available for identification. A recent molecular study using restriction fragment length polymorphism analysis suggests that the three subspecies are polyphyletic, so the elucidation of the strains of *T. brucei* infective to humans requires a more complex explanation. Procyclins are proteins developed in the surface coating of trypanosomes whilst in their tsetse fly vector.

Other forms of human trypanosomiasis also exist but are not transmitted by tsetse. The most notable is American trypanosomiasis; known as **Chagas disease**, which occurs in South America, caused by *Trypanosoma cruzi*, and transmitted by certain insects of the Reduviidae, members of the Hemiptera.

In domestic animals:

Animal trypanosomiasis, also called *nagana* when it occurs in bovine cattle or horses or *sura* when it occurs in domestic pigs, is caused by several trypanosome species. These diseases reduce the growth rate, milk productivity, and strength of farm animals, generally leading to the eventual death of the infected animals. Certain species of cattle are called *trypanotolerant* because they can survive and grow even when infected with trypanosomes although they also have lower productivity rates when infected.

The course of the disease in animals is similar to the course of sleeping sickness in humans. *Trypanosoma congolense* and *Trypanosoma vivax* are the two most important species infecting bovine cattle in sub-Saharan Africa. *Trypanosoma simiae* causes a virulent disease in swine. Other forms of animal trypanosomiasis are also known from other areas of the globe, caused by different species of trypanosomes and transmitted without the intervention of the tsetse fly.

The tsetse fly vector ranges mostly in the central part of Africa. Trypanosomiasis poses a considerable constraint on livestock agricultural development in Tsetse fly infested areas of sub Saharan Africa, especially in west and central Africa. International research conducted by ILRI in Nigeria, the Democratic Republic of the Congo and Kenya has shown that the N'Dama is the most resistant breed.

Control:

The conquest of sleeping sickness and nagana would be of immense benefit to rural development and contribute to poverty alleviation and improved food security in sub-Saharan Africa. Human African trypanosomiasis (HAT) and animal African trypanosomosis (AAT) are sufficiently important to make virtually any intervention against these diseases beneficial.

The disease can be managed by controlling the vector and thus reducing the incidence of the disease by disrupting the transmission cycle. Another tactic to manage the disease is to target the disease directly using surveillance and curative or prophylactic treatments to reduce the number of hosts that carry the disease.

Economic analysis indicates that the cost of managing trypanosomiasis through the elimination of important populations of major tsetse vectors will be covered several times by the benefits of tsetse- free status. Area-wide interventions against the tsetse and trypanosomiasis problem appear more efficient and profitable if sufficiently large areas, with high numbers of cattle, can be covered.

Vector control strategies can aim at either continuous suppression or eradication of target populations. Tsetse fly eradication programmes are complex and logistically demanding activities and usually involve the integration of different control tactics, such as trypanocidal drugs, impregnated treated targets (ITT), insecticide-treated cattle (ITC), aerial spraying (Sequential Aerosol Technique - SAT) and in some situations the release of sterile males (sterile insect technique – SIT). To ensure sustainability of the results, it is critical to apply the control tactics on an area-wide basis, i.e. targetingan entire tsetse population that is preferably genetically isolated.

Control techniques:

Many techniques have reduced tsetse populations, with earlier, crude methods recently replaced by methods that are cheaper, more directed, and ecologically better.

i. **Slaughter of wild animals:**

One early technique involved slaughtering all the wild animals tsetse fed on. For example, the island of Principe off the west coast of Africa was entirely cleared of feral pigs in the 1930s, which led to the extirpation of the fly. While the fly eventually re-invaded in the 1950s, the new population oftsetse was free from the disease.

ii. Land clearing:

Another early technique involved complete removal of brush and woody vegetation from an area. Tsetse tends to rest on the trunks of trees so removing woody vegetation made the area inhospitable to the flies. However, the technique was not widely used and has been abandoned. Preventing regrowth of woody vegetation requires continuous clearing efforts, which is only practical where large human populations are present. The clearing of woody vegetation has come to be seen as an environmental problem more than a benefit.

iii. Pesticide campaigns:

Pesticides have been used to control tsetse starting initially during the early part of the twentieth century in localized efforts using the inorganic metal-based pesticides, expanding after the Second World War into massive aerial- and ground-based campaigns with organochlorine pesticides such as DDT applied as aerosol sprays at Ultra-Low Volume rates. Later, more targeted techniques used *pour-on* formulations in which advanced organic pesticides were applied directly to the backs of cattle. Tsetse populations can be monitored and effectively controlled using simple, inexpensive traps. These often use electric blue cloth, since this colour attracts the flies. Early traps mimicked the form of cattle but this seems unnecessary and recent traps are simple sheets or have a biconical form. The traps can kill by channelling the flies into a collection chamber or by exposing the flies to insecticide sprayed on the cloth. Tsetse are also attracted to large dark colours like the hides of cow and buffaloes. Some scientists put forward the idea that zebra have stripes, not as a camouflage in long grass, but because the black and white bands tend to confuse tsetse and prevent attack.

The use of chemicals as attractants to lure tsetse to the traps has been studied extensively in the late 20th century, but this has mostly been of interest to scientists rather than as an economically reasonable solution. Attractants studied have been those tsetse might use to find food, like carbon dioxide, octenol, and acetone—which are given off in animals' breath and distributed downwind in an *odor plume.* Synthetic versions of these chemicals can create artificial odour plumes. A cheaper approach is to place cattle urine in a half gourd near the trap. For large trapping efforts, additional traps are generally cheaper than expensive artificial attractants.

A special trapping method is applied in Ethiopia, where the BioFarm Consortium (ICIPE, BioVision Foundation, BEA, Helvetas, DLCO-EA, Praxis Ethiopia) applies the traps in a sustainable agriculture and rural development context (SARD). The traps are just the entry point, followed by improved farming, human health and marketing inputs. This method is in the final stage of testing (as per 2006).

In the late 18th century, the Kotokoli Muslims of Togo held a special ritual in order for their child to have a prosperous life. This ritual consisted of mothers killing the tsetse flies and sprinkling them on horned melon. They would feed their children this delicacy. This ritual is still practiced today in some sub-Saharan tribes.

iv. Sterile insect technique:

The sterile insect technique (**SIT**) is a form of pest control that uses ionizing radiation (gamma ray or X ray) to sterilize male flies that are mass-produced in special rearing facilities. The sterile males are released systematically from the ground or by air in tsetse-infested areas, where they mate with wild females, which do not produce offspring. As a result, this technique can eventually eradicate populations of wild flies. SIT is among the most environmentally friendly control tactics available, and is usually applied as the final component of an integrated campaign.

The sustainable removal of the tsetse fly is in many cases the most cost-effective way of dealing with the T&T problem resulting in major economic benefits for subsistence farmers in rural areas. Insecticide-based methods are normally very ineffective in removing the last remnants of tsetse populations, while, on the contrary, sterile males are very effective in finding and mating the last remaining females. Therefore, the integration of the SIT as the last component of an area-wide integrated approach is essential in many situations to achieve complete eradication of the different tsetse populations, particularly in areas of more dense vegetation.

Probable Questions:

1. Describe the morphology of *Phlebotomus s*p.
2. Describe habit and habitat of *Phlebotomus s*p.
3. Describe host preference of *Phlebotomus s*p.
4. Describe life cycle of *Phlebotomus s*p with suitable diagram.
5. Describe pathogenicity and role in disease transmission of *Phlebotomus s*p.
6. Describe morphology of *Glossinia* sp.
7. Describe life cycle of *Glossinia* sp.
8. Describe role of *Glossinia* sp in disease transmission.
9. How *Glossinia* sp population can be controlled?

Suggested Readings:

1. The Insects by Chapman

2. Modern Entomology by D.B. Thembare

3. Economic Zoology by Shukla and Upadhyay

4. The Insects by Gullan and Carnston

5. Introduction to Economic Zoology by Sarkar, Kundu and Chaki.

6. A textbook of Economic Zoology by Aminul Islam.

UNIT VIII

Parasitic insects and Acarines: General remarks on *Tabanus* and head louse in relation to morphology, habit, habitat, life cycle and disease caused by them, mode of transmission

A. *Tabanus* sp. (Common name – Horse fly)

Introduction:

Horse-flies or **horseflies** are true flies in the family **Tabanidae** in the insect order Diptera. They are often large and agile in flight, and the females bite animals, including humans, to obtain blood. They prefer to fly in sunlight, avoiding dark and shady areas, and are inactive at night. They are found all over the world except for some islands and the Polar Regions.

Morphology:

Adults: Tabanidae flies are large flies, up to 2.5cm long with bodies that are usually dark in colour. The dark bodies may have stripes or patches of colour down them or be entirely coloured in some cases. They have broad heads with biting mouth parts and bulging eyes that are often brightly coloured. The mouthparts are adapted to biting a sucking blood, and always pointed ownwards. They consist of paired mandibles and maxillae which are used for cutting and rasping to create a feeding hole. Blood is then sucked using a protruding hypopharynx. The mouthparts are short and deal roughly with the host; this is often the cause of pain for the host. Only females take a blood meal, males lack mandibles and may only feed on honeydew and nectar. The wings of Tabanidae flies havea distinctive venation.

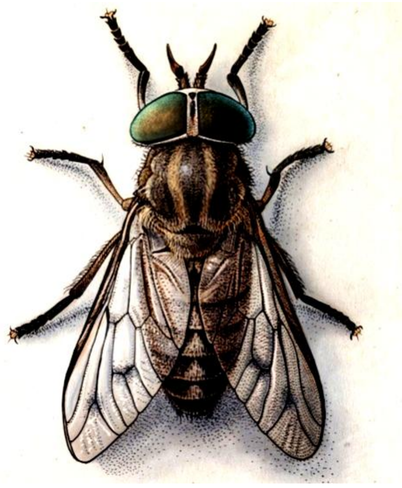


Fig: External features of Horse fly

Larvae: Tabanidae larvae are large, 1.5 - 3cm in length with large biting mandibles. They are off- white in colour with longitudinal striations on the cuticle. There are paired unsegmented appendages, psuedopods, along the body to assist in movement. The posterior of the larvae usually has a respiratory siphon present.

Eggs: Eggs are an off white colour and cigar shaped. They can be between 1 - 3 mm long.

Habit and Habitat

Horse fly females are aggressive blood feeders, while males do not consume blood but feed on pollen and plant nectars. Female horse flies usually bite large, non-moving mammals on the legs or body. Deer flies, in contrast, attack moving hosts and typically target high on the body, like the head or neck. They rarely bite near the head. Horse flies have a range of hosts that include mammals of almost all sizes, livestock, humans, pets and birds. Should a female horse fly be interrupted when attempting to feed, they will fly off but quickly return to bite again, or go to another host to consume a complete blood meal. Horse fly larvae studied by field researchers feed on midges, crane flies and even other horse fly larvae. Because of their cannibalistic behaviours, horse fly larvae are usually found living alone. Deer fly larvae, on the other hand, usually live in groups. Pupae do not feed. Similar to other blood-sucking insects such as mosquitoes for example, female horse flies use both chemical and visual cues to locate hosts. Carbon dioxide expelled by warm-blooded animals provides a long-range cue to attract flies from a distance, while visual cues such as motion, size, shape and dark colour function to attract horse flies from shorter distances. Horse fly development sites are freshwater and salt water marshes and streams, moist forest soils and even moist decomposing wood. Females usually deposit egg masses on wet soil or vegetation that overhangs water. Larvae are active in moist or wet organic matter and look similar to house fly maggots.

Diet and biting behaviour

Adult horse-flies feed on nectar and plant exudates, and some are important pollinators of certain specialised flowers. Both males and females engage in nectar feeding, but in addition to this, females of most species are anautogenous, meaning they require a blood meal before they are able to reproduce effectively. To obtain the blood, the females bite animals, including humans, while the males are harmless. It takes the female about six days to fully digest its blood meal and after that it needs to find another host. It seems that the flies are attracted to a potential victim by its movement, warmth, and surface texture, and by the carbon dioxide it breathes out. The flies mainly choose large mammals such as cattle, horses, camels, and deer, but few are species specific. They have also been observed feeding on smaller mammals, birds, lizards and turtles, and even on animals that have recently died. Because their bite is irritating to the victim, they are often brushed off, and may have to visit multiple hosts to obtain sufficient blood. This behaviour means that they may carry disease-causing organisms from one host to another.

The mouthparts of females are of the usual Dipteran form and consist of a bundle of six chitinous stylets that, together with a fold of the flesh labium, form the proboscis. On either side of theseare two maxillary palps. When the insect lands on an animal it grips the surface with its clawed feet, the labium is retracted, the head is thrust downwards and the stylets slice into the flesh. Some of these have sawing edges and muscles can move them from side-to-side to enlarge the wound. Saliva containing anticoagulant is injected into the wound to prevent clotting. The blood that flows from the wound is lapped up by another mouthpart which functions as a sponge. Horsefly bites can be painful for a day or more; fly saliva may provoke allergic reactions such as hives and difficulty with breathing. Tabanid bites can make life outdoors unpleasant for humans, and can reduce milk output in cattle. They are attracted by reflections from water which are polarized, making them a particular nuisance near swimming pools. Since tabanids prefer to be in sunshine, they normally avoid shaded places such as barns, and are inactive at night. Attack patterns vary with species: Large species of ankles, legs or backs of knees; have a high buzzing note. It has been suggested that the striped hides of reduce their attractiveness to horsehides. The closer together the stripes, the fewer flies are visually attracted; the zebra's legs have particularly fine striping, and this is the shaded part of the body that is most likely to be bitten by the other, unstriped equids. This does not preclude the possible use of stripes for other purposes such as signalling or camouflage.

Life Cycle:

Mating often occurs in swarms, generally at landmarks such as day, and type of landmark, used for mating swarms is specific to particular species. Eggs are laid on stones or vegetation near water, in clusters of up to one thousand, especially on emergent water plants. The eggs are white at first but darken with ages. They hatch after about six days, the emerging larvae using a special hatching spike to open the egg case. The larvae fall into the water or onto the moist ground below.

Chrysops species develop in particularly wet locations while *Tabanus* species prefer drier places. The larvae are legless grubs, tapering at both ends. They have small heads and eleven or twelve segments and moult six to thirteen times over the course of up to a year or more. In temperate species, the larvae have a quiescent period during winter (diapause) while tropical species breed several times a year. In the majority of species they are white, but in some, they are greenish or brownish, and they often have dark bands on each segment. A respiratory siphon at the hind end allows the larvae to obtain air when submerged in water. Larvae of nearly all species are carnivorous, often cannibalistic in captivity, and consume worms, insect larvae, and arthropods. The larvae may be parasitized by nematodes, flies of the families Bombyliidae and Tachinidae; and Hymenoptera in the family Pteromalidae. When fully developed, the larvae move into drier soil near the surface of the ground to pupate.

The pupae are brown and glossy, rounded at the head end and tapering at the other end. Wing and limb buds can be seen and each abdominal segment is fringed with short spines. After about two weeks, metamorphosis is complete, the pupal case splits along the thorax and the adult fly emerges. Males usually appear first, but when both sexes have emerged, mating takes place, courtship starting in the air and finishing on the ground. The female needs to feed on blood before depositing her egg mass.

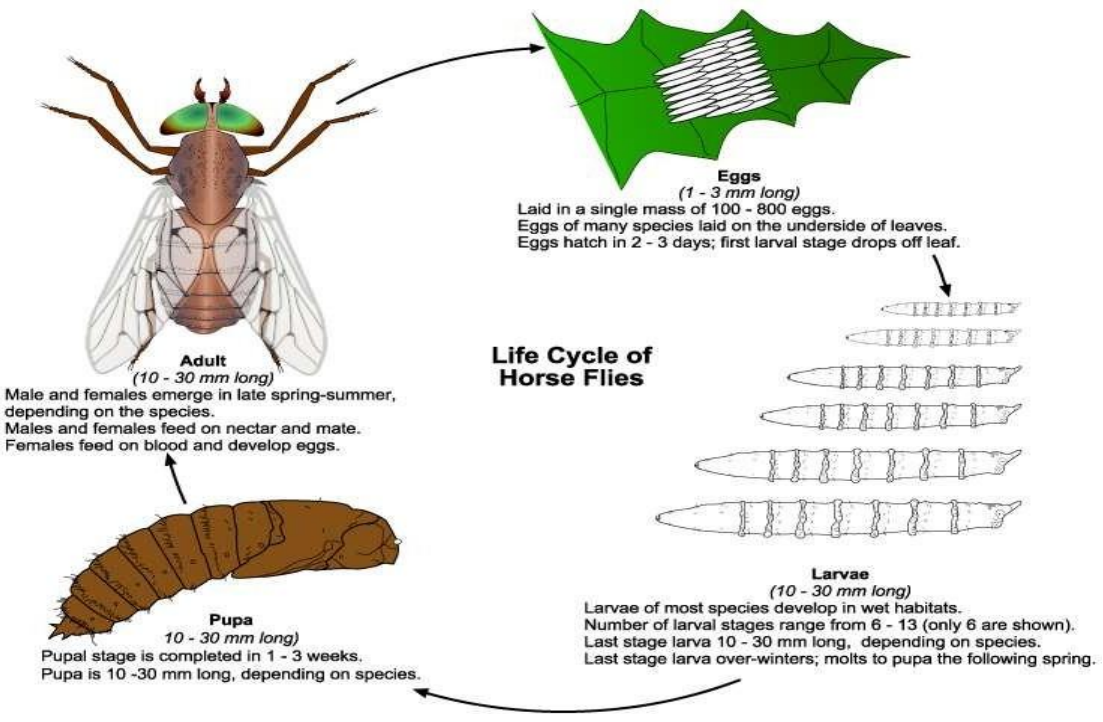


Fig: Life cycle of *Tabanus* sp.

Pathogenesis:

The Tabanidae flies in themselves are responsible for painful, irritating bites which can cause distress to the animal in question. They are most active on hot, sunny days and locate their prey by sight using their large bulbous eyes. As well as causing irritation when biting the flies act as mechanical vectors for a number of other pathogens;

a. Bacteria such as anthrax and pasteurellosis

b. Viruses such as Equine infectious anaemia and African horse sickness

c. Rickettsiales, such as anaplasmosis

The Tabanidae flies may also act as intermediate host for some trypanosome species.

Disease transmission:

Tabanids are known vectors for some blood-borne bacterial, viral, protozoan and worm diseasesof mammals, such as the equine infectious anaemia virus and various species of *Trypanosoma* which cause diseases in animals and humans. Tabanids are known to transmit anthrax among cattle and sheep, and tularemia between rabbits and humans. Blood loss is a common problem in some animals when large flies are abundant. There are anecdotal reports of horse-fly bites leading to fatal anaphylaxis in humans, an extremely rare occurrence.

Control:

Controlling horse flies is nearly impossible. The use of insecticides to kill larvae is not an option because the vast majority of species develop in natural habitats in which insecticides cannot be applied due to environmental concerns. Even if they could be used, insecticides would be ineffective in controlling larvae because they are widely dispersed in a developmental site. The use of insecticides against adult horse flies is not a realistic option because they are relatively large to very large and unaffected by the rate of insecticide that can be applied according to product label. At best, an insecticide application aimed at adults might produce a minor and temporary reduction in biting. A number of trapping devices have been used to capture adults, but their value is limited to sampling. At best, trapping devices produce temporary, minor relief from female horse flies.

Malaise traps are most often used to capture them and these can be modified with the use of baits and attractants that include carbon dioxide or octenol. A dark shiny ball suspended below them that moves in the breeze can also attract them and forms a key part of a modified "Manitoba trap" that is used most often for trapping and sampling Chemical: Cattle can be treated with pour-on pyrethroids which may repel the flies, and fitting them with insecticide impregnated eartags or collars has had some success in killing the insects. Again, repellents, including those containing DEET, have very little or no effect in deterring adult horse flies. Wearing a thick long sleeve shirt, thick pants, and a heavy hat may provide some protection against bites when entering habitats that support large numbers of adult horse flies, but they can be very annoying as they attempt to take blood meals.

B. *Pediculus humanus capitis* (Common Name: Head louse)

Introduction:

The head louse (*Pediculus humanus capitis*) is an obligate ectoparasite of humans that causes head lice infestation. Head lice are wingless insects spending their entire lifeon the human scalp and feeding exclusively on human blood. Humans are the only known hosts of this specific parasite, while chimpanzees host a closely related species, *Pediculus schaeffi*. Other species of lice infest most orders of mammals and all orders of birds, as well as other parts of the human body.

Lice differ from other hematophagic ectoparasites such as fleas in spending their entire life cycle on a host. Head lice cannot fly, and their short stumpy legs render them incapable of jumping, or even walking efficiently on flat surfaces. The non-disease-carrying head louse differs from the related disease-carrying body louse (*Pediculus humanus humanus*) in preferring to attach eggs to scalp hair rather than to clothing.

The two subspecies are morphologically almost identical but do not normally interbreed, although they will do so in laboratory conditions. From genetic studies, they are thought to have diverged as subspecies about 30,000–110,000 years ago, when many humans began to wear a significant amount of clothing. A much more distantly related species of hair-clinging louse, the pubic or crab louse (*Pthirus pubis*), also infests humans. It is visually different from the other two species and is much closer in appearance to the lice which infest other primates.

Head lice (especially in children) have been, and still are, subject to various eradication campaigns. Unlike body lice, head lice are not the vectors of any known diseases. Except for rare secondary infections that result from scratching at bites, head lice are harmless, and they have been regarded by some as essentially a cosmetic rather than a medical problem. It has even been suggested that head lice infestations might be beneficial in helping to foster a natural immune response against lice which helps humans in defense against the far more dangerous body louse, which is capable of transmission of dangerous diseases.

Systematic position:

Kingdom: Animalia
Phylum: Arthropoda
Class: Insecta
Order: Phthiraptera
Family: Pediculidae
Genus: *Pediculus*
Species: *humanus*
Subspecies: *P. h. capitis*

Morphology:

Like other insects of the suborder Anoplura, adult head lice are small (2.5–3 mm long), dorsoventrally flattened (see anatomical terms of location), and entirely wingless. The thoracic segments are fused, but otherwise distinct from the head and abdomen, the latter being composed of seven visible segments. Head lice are grey in general, but their precise colour varies according to the environment in which they were raised. After feeding, consumed blood causes the louse body to take on a reddish colour.

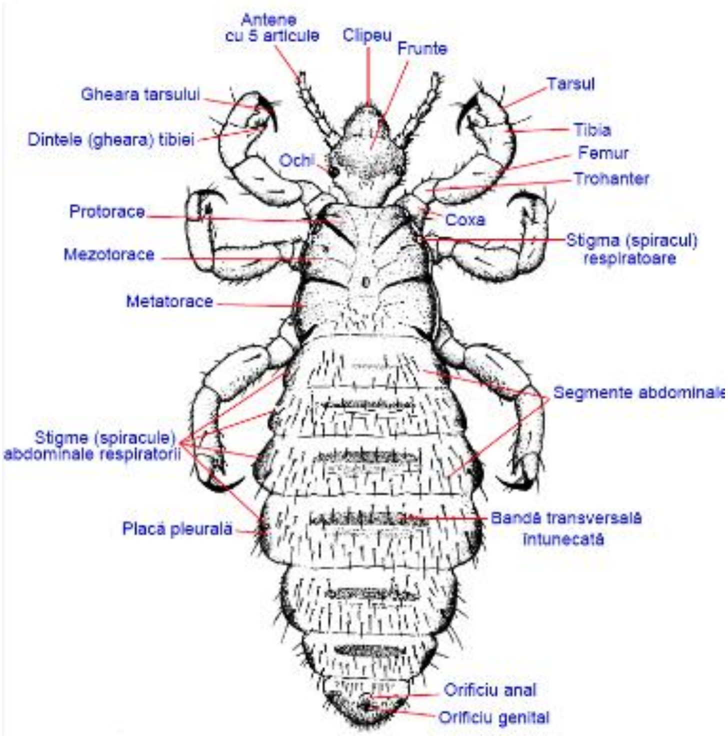


Fig: External morphology of Head louse

i. Head

One pair of antennae, each with five segments, protrudes from the insect's head. Head lice also have one pair of eyes. Eyes are present in all species within *Pediculidae* (the family of which the head louse is a member) but are reduced or absent in most other members of the Anoplura suborder. Like other members of Anoplura, head lice mouth parts are highly adapted for piercing skin and sucking blood. These mouth parts are retracted into the insect's head except during feeding.

ii. Thorax

Six legs project from the fused segments of the thorax. As is typical in Anoplura, these legs are short and terminate with a single claw and opposing "thumb". Between its claw and thumb, the louse grasps the hair of its host. With their short legs and large claws, lice are well adapted to clinging to the hair of their host. These adaptations leave them incapable of jumping, or even walking efficiently on flat surfaces. Lice can climb up strands of hair very quickly, allowing them to move quickly and reach another host.

iii. Abdomen

There are seven visible segments of the louse abdomen. The first six segments each have a pair of spiracles through which the insect breathes. The last segment contains the anus and (separately) the genitalia.

Sex differences:

In male lice, the front two legs are slightly larger than the other four. This specialized pair of legs is used for holding the female during copulation. Males are slightly smaller than females and are characterized by a pointed end of the abdomen and a well-developed genital apparatus visible inside the abdomen. Females are characterized by two gonopods in the shape of a W at the end of their abdomen.

Louse eggs (nit):

Like most insects, head lice are oviparous. Females lay about 3–4 eggs per day. Louse eggs are attached near the base of a host hair shaft. Egg-laying behaviour is temperature dependent and likely seeks to place the egg in a location that will be conducive to proper embryo development (which is, in turn, temperature dependent). In cool climates, eggs are generally laid within 3–5 mm of the scalp surface. In warm climates, and especially the tropics, eggs may be laid 6inches (15 cm) or more down the hair shaft. To attach an egg, the adult female secretes glue from her reproductive organ. This glue quickly hardens into a "nit sheath" that covers the hair shaft and large parts of the egg except for the operculum, a cap through which the embryo breathes. The glue was previously thought to be chitin-based, but more recent studies have shown it to be made of proteins similar to hair keratin. Each egg is oval-shaped and about 0.8 mm in length. They are bright, transparent, tan to coffee coloured so long as they contain an embryo but appear white after hatching. Typically, a hatching time of six to nine days after oviposition is cited by authors. After hatching, the louse nymph leaves behind its egg shell (usually known as nit), still attached to the hair shaft. The empty egg shell remains in place until physically removed by abrasion or the host, or until it slowly disintegrates, which may take 6 or more months.

Nits

The term nit refers to an egg without embryo or a dead egg. Accordingly, on the head of an infestedindividual the following eggs could be found:

Life Cycle:

The lice life cycle of is the period of time between the moment head lice eggs are laid by the female until the moment head lice die. The Life Cycle of the Head Lice lasts about 45 days. Head lice reproduce very quickly. The male is a tireless lover who can fertilize 18 females in a row without having a rest. The females mate several times during their adult life, which can vary from ten to forty days, usually about 20 days. They lay up to 10 lice eggs or nits daily. Mobile head lice populations contain members of up to four developmental stages: three nymphal instars, and the adult (imago).

1. From Egg To Nymph

Head lice incubation period lasts about a week (from 6 to 9 days exactly), which means that head lice eggs or nits hatch about a week after eggs have been laid. Head lice eggs hatch to release a nymph. The latter resembles the adult lice, but of course it is smaller, and it measures about 1 millimeter, the size of a pinhead.

2. From Nymph to Adult Louse

The adult stage is reached after approximately 7 days after three successive molts. Thus, from the laying of the egg to the emergence of adults are 17 days, and the adult will live for about 30-40 days.

Metamorphosis during head lice development is subtle. The only visible differences between different instars and the adult, other than size, is the relative length of the abdomen, which increases with each moult. Aside from reproduction, nymph behaviour is similar to the adult. Nymphs feed only on human blood (hematophagia), and cannot survive long away from a host.

The time required for head lice to complete their nymph development to the imago depends on feeding conditions. At minimum, eight to nine days is required for lice having continuous access to a human host. This experimental condition is most representative of head lice conditions in the wild. An experimental condition where the nymph has more limited access to blood produces more prolonged development, ranging from 12 to 24 days.

3. Adult Stage

The lifespan of an adult louse is about 30 days. This means that head lice, once they have reached the adult stage, will live for about one month. They can only survive this long if on a human head. They need to feed on human blood several times a day. They will die within 48 hours off a human head.

Nymph mortality in captivity is high—about 38%—especially within the first two days of life. In the wild, mortality may instead be highest in the third instar. Nymph hazards are numerous. Failure to completely hatch from the egg is invariably fatal and may be dependent on the humidity of the egg's environment. Death during moulting can also occur, although it is reportedly uncommon. During feeding, the nymph gut can rupture, dispersing the host's blood through out the insect. This results in death within a day or two. It is unclear if the high mortality recorded under experimental conditions is representative of conditions in the wild.

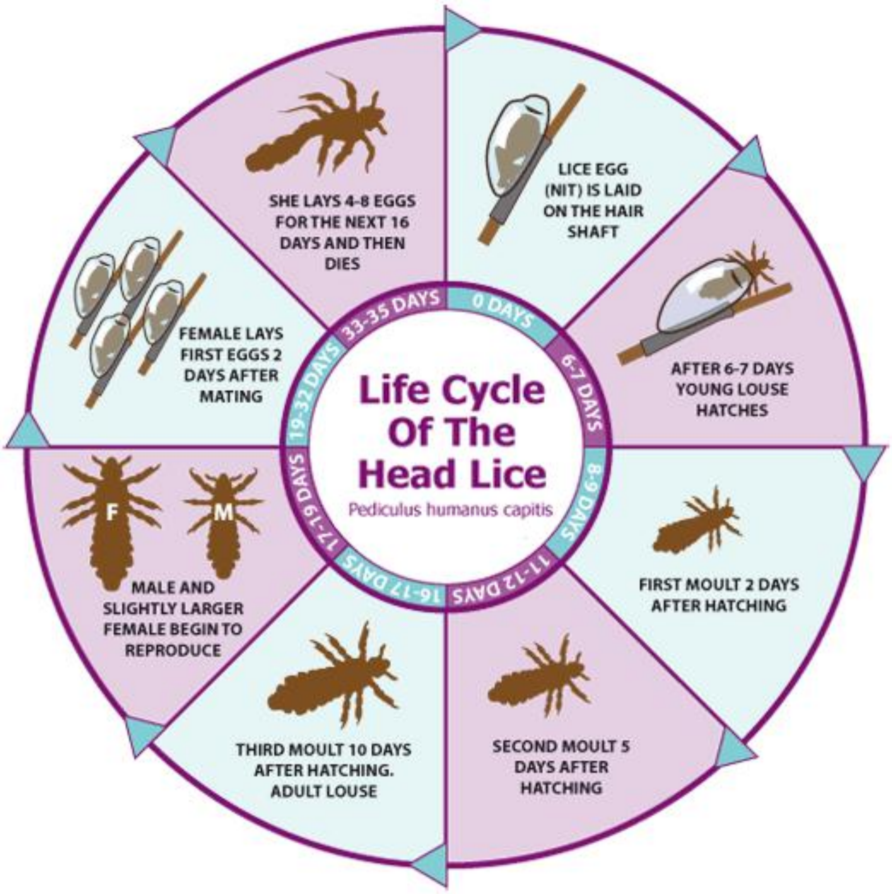


Fig: Life cycle of *Pediculus humanu*

Reproduction and life span:

Copulation in *Pediculus humanus humanus* (*Pediculus humanus capitis* is similar). Female is on top, with the male below. Dilation of the female's vagina has already occurred, and the male's dilator rests against his back (dorsal surface), out of the way. The male vesica, which contains the penis proper (not seen), is fully inserted into the vagina. Note the male's attachment with his specialized claws on the first leg pair to the specialized notch on the female's third leg pair. Adult head lice reproduce sexually, and copulation is necessary for the female to produce fertile eggs. Parthenogenesis, the production of viable offspring by virgin females, does not occur in *Pediculus humanus*. Pairing can begin within the first 10 hours of adult life. After 24 hours, adult lice copulate frequently, with mating occurring during any period of the night or day. Mating attachment frequently lasts more than an hour. Young males can successfully pair with older females, and vice versa.

Experiments with *Pediculus humanus humanus* (body lice) emphasize the attendant hazards of lice copulation. A single young female confined with six or more males will die in a few days, having laid very few eggs. Similarly, death of a virgin female was reported after admitting a male to her confinement. The female laid only one egg after mating, and her entire body was tinged with red—a condition attributed to rupture of the alimentary canal during the sexual act. Old females frequently die following, if not during, intercourse. A single louse has a thirty-day life cycle beginning from the moment the nit is laid until the adult louse dies.

Habit:

All stages are blood-feeders and bite the skin four to five times daily to feed. They inject saliva which contains an anti-coagulant and suck blood. The digested blood is excreted as dark red frass. Although any part of the scalp may be colonized, lice favour the nape of the neck and the area behind the ears, where the eggs are usually laid. Head lice are repelled by light and will move towards shadows or dark-coloured objects in their vicinity.

Disease caused by head lice:

Head lice are not known to transmit any disease and therefore are not considered a health hazard. Head lice infestations can be asymptomatic, particularly with a first infestation or when an infestation is light. Itching ("pruritus") is the most common symptom of head lice infestation and is caused by an allergic reaction to louse bites. It may take 4–6 weeks for itching to appear the first time a person has head lice.

Other symptoms may include:

- a tickling feeling or a sensation of something moving in the hair;
- irritability and sleeplessness; and
- sores on the head caused by scratching. These sores caused by scratching can sometimesbecome infected with bacteria normally found on a person's skin.

Transmission:

Lice have no wings or powerful legs for jumping, so they move by using their claw-like legs to transfer from hair to hair. Normally head lice infest a new host only by close contact between individuals, making social contacts among children and parent-child interactions more likely routes of infestation than shared combs, hats, brushes, towels, clothing, beds or closets. Head-to head contact is by far the most common route of lice transmission.

Diagnosis of head lice infestation:

Head lice are most frequently located on the scalp behind the ears and near the neckline at the back of the neck. Head lice hold on to hair with hook-like claws that are found at the end of each of their six legs. Head lice are rarely found on the body, eyelashes, or eyebrows. Head lice can be detected by looking closely through the hair and scalp for nits, nymphs, or adults. Locating a nymph or adult may be difficult; there are usually only a few of them, and they can move quickly from searching fingers. However, the presence of nits close to the scalp confirms that a person is infested. If the nits are located more than ¼ inch from the scalp, the infestation is probably an old one. If you are not sure whether or not a person has head lice, the diagnosis should be made by a health care professional, school nurse, or a professional from the local health department or agricultural extension service. The nits of head lice are easily visible with a microscope.

Probable Questions:

1. Describe life cycle of *Tabanus* sp.
2. Describe morphology of *Tabanus* sp.
3. Describe habit and habitat of *Tabanus* sp.
4. Describe pathogenicity of *Tabanus* sp.
5. describe role of *Tabanus* sp in disease transmission.
6. How *Tabanus* sp can be controlled?
7. Describe morphology of head louse.
8. Describe life cycle of head louse.
9. Describe pathogenicity of head louse.
10. How head louse infection can be diagnosed?

Suggested Readings:

1. The Insects by Chapman
2. Modern Entomology by D.B. Thembare
3. Economic Zoology by Shukla and Upadhyay
4. The Insects by Gullan and Carnston
5. Introduction to Economic Zoology by Sarkar, Kundu and Chaki.
6. A textbook of Economic Zoology by Aminul Islam.

UNIT IX

Parasitic insects and Acarines: General remarks on mites in relation to morphology, habitat, life cycle and diseases caused by them

Objective:

In this unit we will discuss about general remarks on mites in relation to morphology, habitat, life cycle and diseases caused by them.

Introduction

Mites are among the smallest arthropods with most barely visible without magnification. Mites are closely related to ticks, but they are tissue-juice feeders, not blood-feeders, and do not transmit as broad a variety of infectious microbial diseases. In fact, the only infectious diseases transmitted by mites are rickettsial pox and scrub typhus. The most common ectoparasitic dermatoses caused by mites are chiggers and scabies.

General Morphology of mites:

External

Mites are tiny members of the class Arachnida; most are in the size range 0.25 to 0.75 mm (0.01 to 0.03 in) but some are larger and some are no bigger than 0.1 mm (0.004 in) as adults. The body plan is similar to that of ticks in having two regions, a cephalothorax (with no separate head) or prosoma, and an opisthosoma or abdomen (Fig 1). Segmentation has almost entirely been lost and the prosoma and opisthosoma are fused, only the positioning of the limbs indicating the location of the segments.

The body is covered with tactile hairs or scales. There is no true head, but the mouth parts are borne on an anterior part, called a gnathosoma or capitulum. This is not a head and does not contain the eyes or the brain, but is a retractable feeding apparatus consisting of the chelicerae, the pedipalps and the oral cavity. It is covered above by an extension of the body carapace and is connected to the body by a flexible section of cuticle. There are two pairs of mouth parts, the chelicerae and the pedipalps or palpi. The mouthparts differ between taxa depending on diet; in some species the appendages resemble legs while in others they are modified into chelicerae-like structures. The oral cavity connects posteriorly to the mouth and pharynx. Eyes may be present or absent. Most mites have four pairs of legs, each with six segments, which may be modified for swimming or other purposes.

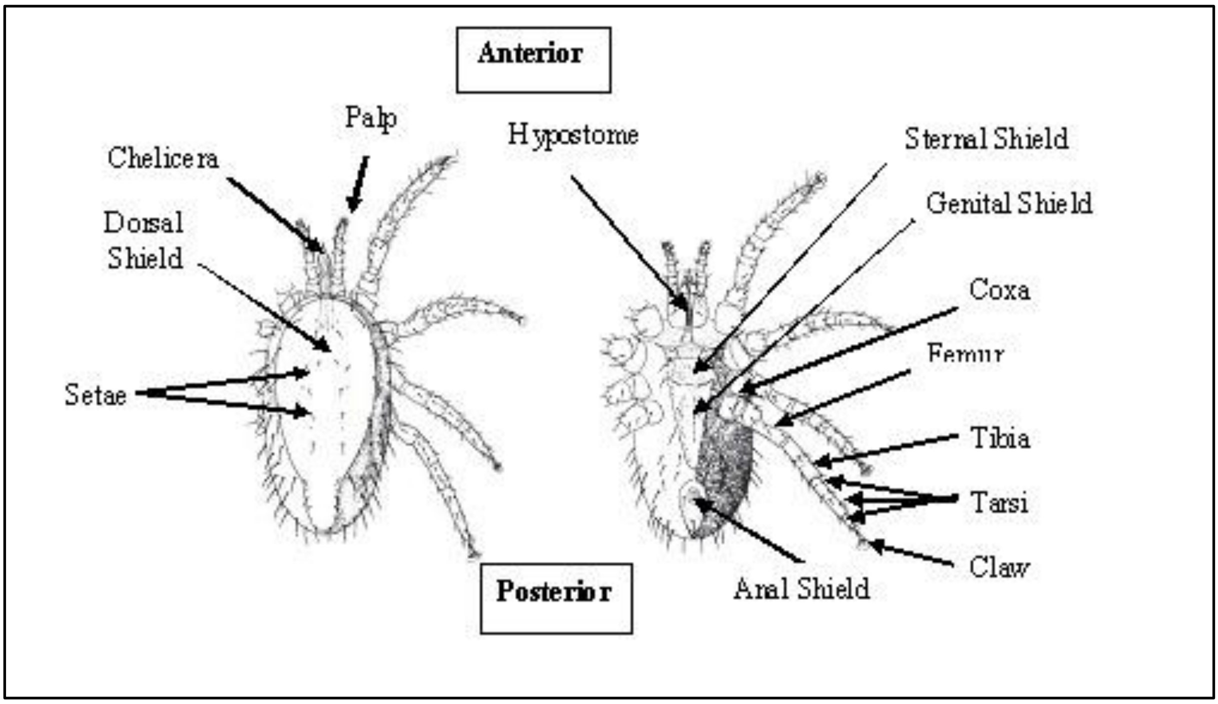


Fig 1: General structure of mite

The dorsal surface of the body is clad in hardened tergites and the ventral surface by hardened sclerites; sometimes these form transverse ridges. The gonopore (genital opening) is located on the ventral surface between the fourth pair of legs. Some species have one to five median or lateral eyes but many species are blind and slit and pit sense organs are common. Both body and limbs bear setae (bristles) which may be simple, flattened, club-shaped or sensory. Mites are usually some shade of brown, but some species are red, orange, black or green, or some combination of these colours.

Internal

Mites have a typical arachnid digestive system, although some species lack an anus: they do not defecate during their short lives. The circulatory system consists of a network of sinuses and lacks a heart, movement of fluid being driven by the contraction of body muscles. Gas exchange is carried out across the body surface, but many species additionally have between one and four pairs of tracheae, the spiracles being located in the front half of the body. The excretory system includes a nephridium and one or two pairs of Malpighian tubules.

Life History of Mites:

Many mites are free living, some are predaceous and many are parasitic on other animals during all or part of their life cycle. Some of these ranks among the most important disease vectors and some act as intermediate hosts of Protozoans or Helminths.

There are usually four stages in the development (i.e. life history) of mites—egg, larva, nymph and adult. However, there are usually a single larval stage and two nymphal stages (i.e., the protonymph and deutonymph) in the life cycle of a mite. The number of nymphal generation may be less or more in some species of mites.The sexes are separate in mites; males have a pair of testes in the mid-region of the body, each connected to the gonopore by a vas deferens, and in some species there is a chitinous penis; females have a single ovary connected to the gonopore by an oviduct, as well as a seminal receptacle for the storage of sperm. In most mites, sperm is transferred to the female indirectly; the male either deposits a spermatophore on a surface from which it is picked up the female, or he uses his chelicerae or third pair of legs to insert it into the female's gonopore. In some of the Acariformes, insemination is direct using the male's penis.

The eggs are laid in the substrate, or wherever the mite happens to live. They take from two to six weeks to hatch, and the first stage larvae have six legs. After three moults, the larvae become nymphs, with eight legs, and after a further three moults, they become adults. Longevity varies between species, but the lifespan of mites is short as compared to many other arachnids.

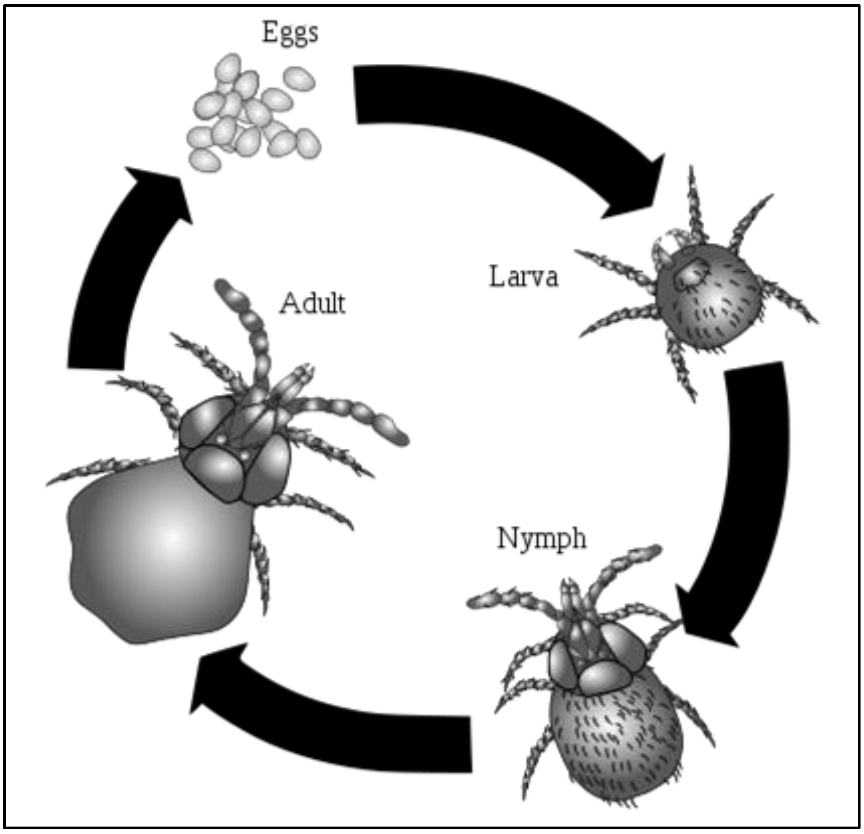


Fig 2: Life cycle of mite

General Idea about Mites as Vectors:

There are some species of mites which are important from the stand point of veterinary science as they cause transmission of several diseases. There are also few species of mites which help in the transmission of human diseases including allergy.

The important vector species of mites will be discussed:

1. Red bugs:

There is probably no creature on earth that can cause more torment for its size than a red bug. These mites are also suspected on epidemiological grounds of transmitting epidemic hemorrhagic fever.

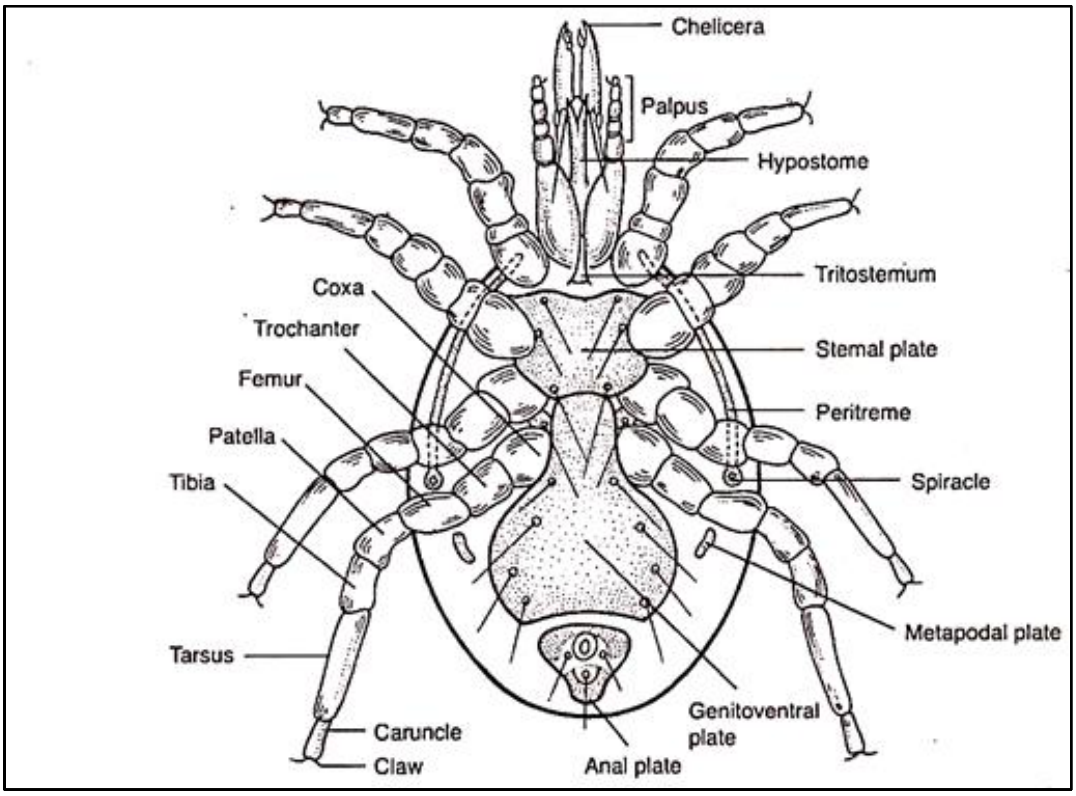


Fig 3: Generalized Mesostigmatide Mite

The red bugs are the six-legged larvae of mites of the family Trombiculidae under order Prostimata, comprise a group of mites which are parasitic to human beings only at their larval stage. The nymphs and adults are free living, feeding on insect eggs or minute insect larvae. In Siberia, Korea, Manchuria scrub typhus is a viral disease which causes fever, kidney damage etc. and is fatal in 5% of cases.The important chigger mite, *Trombiculaakamushi* is responsible for causing scrub typhus to human beings but *T. pelkini, T. goldii, T. wichtnanni*etc create human dermatitis.

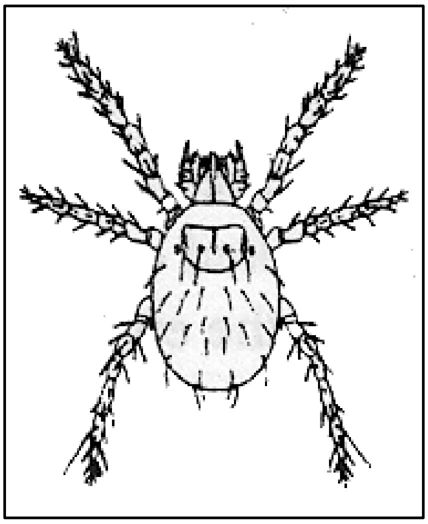
The larval mite acts as the vector in carrying the pathogen, *Rickettsia tsutsugamushi* causing scrub typhus. They transmit the pathogen from small mammals to human beings (hosts). The larval mites receive the pathogens by means of trans-ovarian transmission from the mother.

Now the larvae penetrate the epidermis by means of mouth parts and introduce the salivary secretion containing the pathogen into the host. The Escher is the primary lesion which appears just at the point of red-bug bite.

It is characterized by headache, apathy, fever, lymph adenitis, general malaise, enlarged spleen, deafness, nervous turbances etc. The Escher enlarges and becomes necrotic in the center and red rashes appear on the trunk that may spread to extremities.

2. Chiggers

Chiggers are the larvae of a family of mites that are sometimes called red bugs. The adults are large, red mites often seen running over pavement and lawns. Chiggers are extremely small (0.5 mm) and are difficult to see without magnification. The six-legged larvae are hairy and yellow-orange or light red. They are usually encountered outdoors in low, damp places where vegetation is rank and grass and weeds are overgrown. Some species also infest drier areas, however, making it difficult to predict where an infestation will occur.



Chiggers overwinter as adults in the soil, becoming active in the spring. Eggs are laid on the soil. After hatching, the larvae crawl about until they locate and attach to a suitable host. The larvae do not burrow into the skin, but inject a salivary fluid which produces a hardened, raised area around them. Body fluids from the host are withdrawn through a feeding tube. Larvae feed for about 4 days and then drop off and molt to nonparasitic nymphs and adults. Chiggers feed on a variety of wild and domestic animals, as well as humans. The life cycle (from egg to egg) is completed in about 50 days.

Most people react to chigger bites by developing reddish welts within 24 hours. Intense itching accompanies the welts, which may persist for a week or longer if not treated. Bites commonly occur around the ankles, waistline, armpits, or other areas where clothing fits tightly against the skin. Besides causing intense itching, chigger bites that are scratched may result in infection and sometimes fever. Chiggers in North America are not known to transmit disease.

Persons walking in chigger-infested areas can be protected by treating clothing (cuffs, socks, waistline, and sleeves) or exposed skin with tick repellents. Some repellents should only be used on clothing; and it is important to follow label directions. People who suspect they may have been attacked by chiggers should take a soapy bath immediately and apply antiseptic to any welts. A local anesthetic will provide temporary relief from itching.

Regular mowing and removal of weeds and brush make areas less suitable for chiggers and their wild hosts. Mowing also enhances penetration and performance of miticides, should they be required. Chigger populations can be further reduced by treating infested areas with residual miticides. Applications should be thorough but restricted to areas frequented and suspected of being infested.

3. Itch and Eczema creating mites (*Sarcoptes scabiei*):

The minute rounded or oval, short legged, flattened mites of the family Sarcoptidae under the suborder Sarcoptiformes are the cause of scabies or "itch" in man. This mite creates eczema and unbearable itches leading to mange of man.

The cuticle of the mite is delicately sculptured, number of bristles is few, eyes and trachea are absent. Capitulum is well developed. The legs are short and stumpy and are provided with sucker like adhesive pads (Fig 6 and 7).

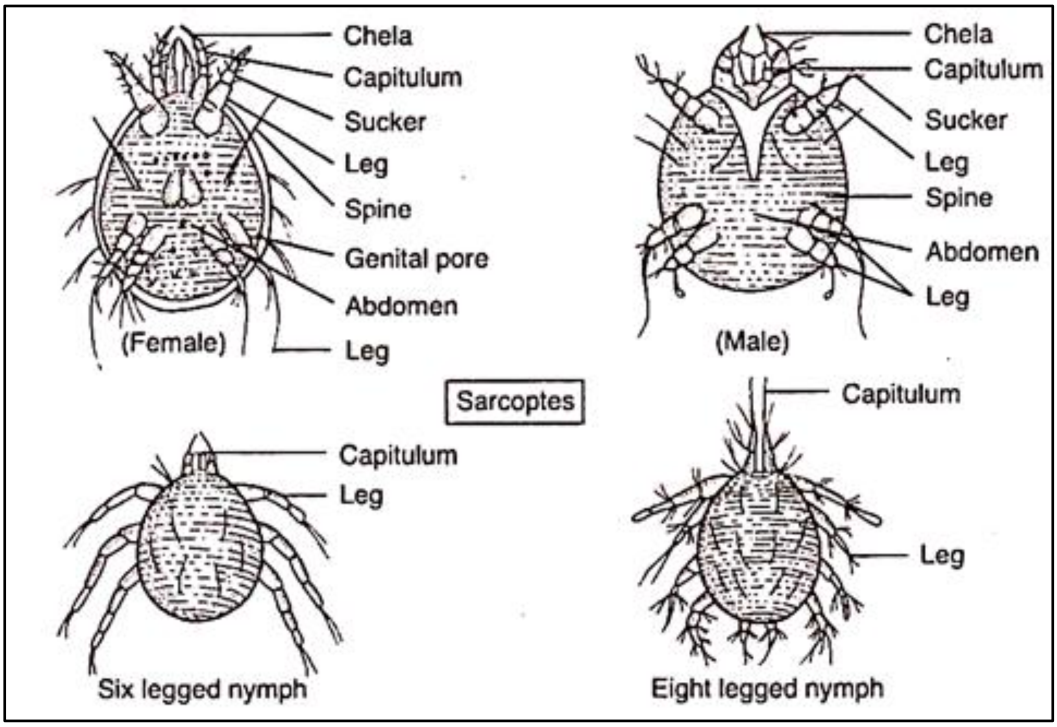


Fig 4: Structure of *Sarcoptes scabiei*

When the female mite, comes in contact with the hands or feet of human, it excavates thin tortuous tunnels in the epidermis. The tunnel mea-sures a few mm to over an inch in length and is usually gray from the eggs and excrement deposited by the female as she burrows. The daily excavations of a mite are about 2-3 mm.

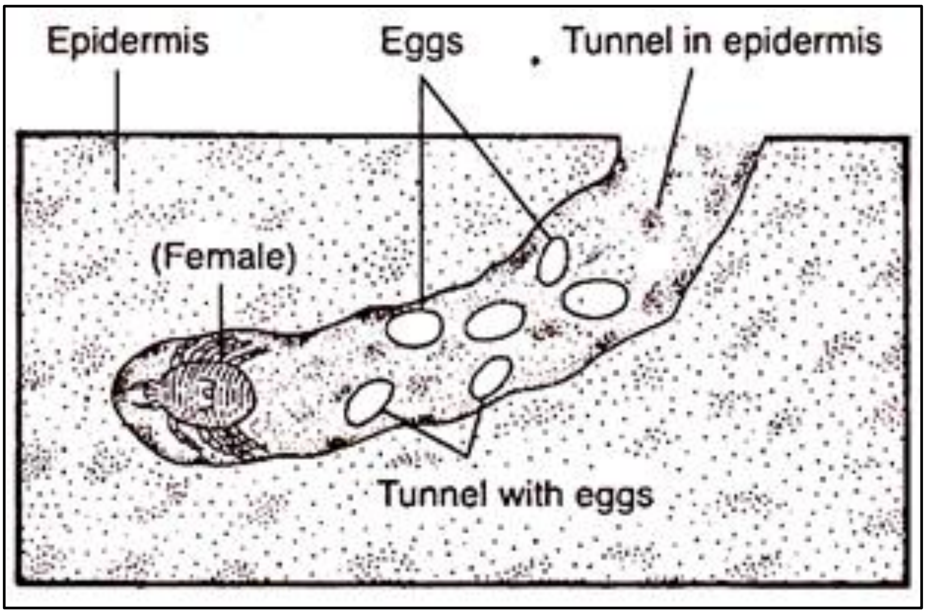


Fig 5: Tunnel of Itch Mite in Human Skin, showing female depositing egg

The life span of a mite is about 4 weeks and the young impregnated females make fresh excavations of their own and the process goes on. As a result the tissues below the epidermis are destroyed and finally itching begins. The itching is so severe that the patient cannot sleep at night and sometimes the infection becomes unbearable.

Repeated infection of itching turns into eczema. *Sarcoptes scabiei* generally invades the skin of the wrist though external genetalia, breasts, legs, thorax and other organs may be attacked by this mite.

4. The Tropical rat mite:

The tropical rat mite, *Ornithonyssus bacoti* (formerly *Liponyssus* or *Bdellonyssus*) are important parasites of birds and rodents and are concerned in transmission of certain rickettsial and viral diseases. They have relatively narrow dorsal shields and chelicerae that end in pincers in both sexes.

They act as vectors of Q. fever (query fever) by transmitting the pathogen, *Coxiella bumetti*. The blood sucking protonymph is the infective stage of the disease. This tropical rat mite plays a minor role in transmission among reservoir hosts, and occasionally to human beings, of endemic typhus, rickettsial pox, Q. fever, plague, etc. and it also acts as the intermediate host of the filaria of cotton rats, *Liptomosoides*.

5. **Human biting mites:**

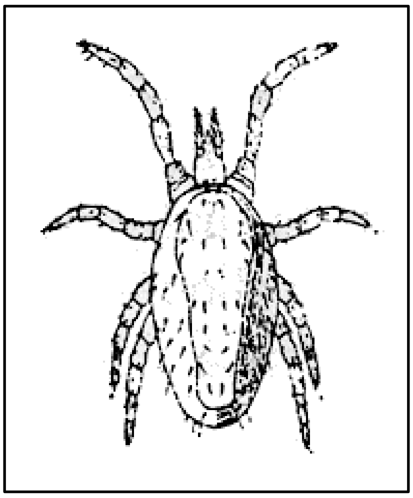
Several types of mites are associated with cases of skin dermatitis in humans. The tropical rat mite, *Ornithonyssus bacoti*, is one of the most common houses invading species. The tropical fowl mite, *Ornithonyssus bursa*, and northern fowl mite, *Ornithonyssus sylviarum*, are also frequently encountered in homes. The latter two species are found principally on domestic or wild birds. The house mouse mite, *Liponyssoides sanguineus*, may also be found in structures with house mouse infestations. The tropical rat mite is a parasite on rats. Although none of these species are truly parasitic on humans, they bite people readily, often producing dermatitis and itching.

Rat and bird mite infestations occur in structures where rat or bird nests are located. Infestations are sometimes first noticed following extermination, or after the natural hosts have died or left the structure. Infestations may also occur where heavy mite infestations have developed around a rodent or bird nest. Occasionally rodent or bird mites may be found on rodents kept as pets.

Rat mites are small, approximately the size of the period at the end of this sentence. They move actively and can be picked up with a wet finger, brush or piece of sticky tape. Distinguishing between different species of *Ornithonyssus* mites to determine whether birds or rodents are the likely source is difficult and requires special expertise. The first course of action when faced with a suspected biting mite problem is to look for all potential bird or rodent sources and collect some of the mites, if possible.

6. **Bird and Rodent mites**

Parasitic mites that occasionally infest buildings are usually associated with wild or domestic birds or rodents. Bird and rodent mites normally live on the host or in their nests but migrate to other areas of the structure when the animal dies or abandons the nest. Rodent mites often become a nuisance after an infestation of mice or rats has been eliminated. People usually become aware of the problem when they are attacked by mites searching for an alternate food source. Their bites cause moderate to intense itching and irritation. Rodent and bird mites are very tiny, but usually can be seen with the naked eye. They are about the size of the period at the end of this sentence.



The first step in controlling bird or rodent mites is to eliminate the host animals and remove their nesting sites. Often, the nests will be found in the attic, around the eaves and rafters, or in the gutters or chimney. Gloves should be used when handling dead animals. A respirator should also be worn when removing nest materials to avoid inhaling fungal spores and other potential disease-producing organisms associated with the droppings.

After nests are removed, the areas adjacent to the nest should be sprayed or dusted with a residual insecticide such as those products labeled for flea control. Space or ULV treatments with non-residual materials (e.g., synergized pyrethrins) can be used in conjunction with residual sprays. Space treatments are especially useful when the mite infestation has dispersed widely from the nesting site. In this case, more extensive treatment with residual and non-residual insecticides may also be necessary in other areas of the structure where mites are observed. A vacuum cleaner or cloth moistened with alcohol can be used to eliminate mites crawling on open surfaces.

Mites are tiny arthropods, related to ticks. Several types of mites can be found in homes and of these a few may bite humans. Most mites are harmless predators of insects, or feeders on decaying plant material. Some pest mites feed on stored products like cheese and grain. Others are merely nuisance pests, accidentally entering homes from their normal outdoor habitat. Only a few mite species are parasitic on birds or mammals, but these can occasionally become biting pests in homes. Identifying the type of mite and/or likely host is the first step in solving an indoor mite infestation.

Disease transmitted by mites:

1. Scabies

Scabies is a skin infestation caused by a mite known as the *Sarcoptes scabiei*. These microscopic mites can live on your skin for months. They reproduce on the surface of your skin and then burrow into the upper layer of the skin but never below the stratum corneum and lay eggs. The burrows appear as tiny raised serpentine lines that are grayish or skin-colored and can be a centimeter or more in length. This causes an itchy, red rash to form on the skin. Other races of scabies mites may cause infestations in other mammals, such as domestic cats, dogs, pigs, and horses.

There are approximately 130 million Trusted Source cases of scabies in the world at any given time. While it’s a highly contagious condition that can easily be passed from one person to another through direct skin contact, scabies isn’t a sexually transmitted disease. The infestation of mites may also be transmitted through infested clothing or bedding. Intimate contact isn’t necessary. Although scabies can be bothersome, they can usually be eliminated effectively.

Causal Agent:

Sarcoptes scabiei var. *hominis*, the human itch mite, is in the arthropod class Arachnida, subclass Acari, family Sarcoptidae.

It should be noted that races of mites found on other animals may cause a self-limited infestation in humans with temporary itching due to dermatitis; however they do not multiply on the human host.

Life Cycle:

Sarcoptes scabiei undergoes four stages in its life cycle: egg, larva, nymph and adult (Fig 6).

Eggs: Females deposit 2-3 eggs per day as they burrow under the skin. Eggs are oval and 0.10 to 0.15 mm in length and hatch in 3 to 4 days. After the eggs hatch, the larvae migrate to the skin surface and burrow into the intact stratum corneum to construct almost invisible, short burrows called molting pouches.

Larva: The larval stage, which emerges from the eggs, has only 3 pairs of legs and lasts about 3 to 4 days. After the larvae molt, the resulting nymphs have 4 pairs of legs. This form molts into slightly larger nymphs before molting into adults.

Nymph: Larvae and nymphs may often be found in molting pouches or in hair follicles and look similar to adults, only smaller.

Adult: Adults are round, sac-like eyeless mites. Females are 0.30 to 0.45 mm long and 0.25 to 0.35 mm wide, and males are slightly more than half that size.

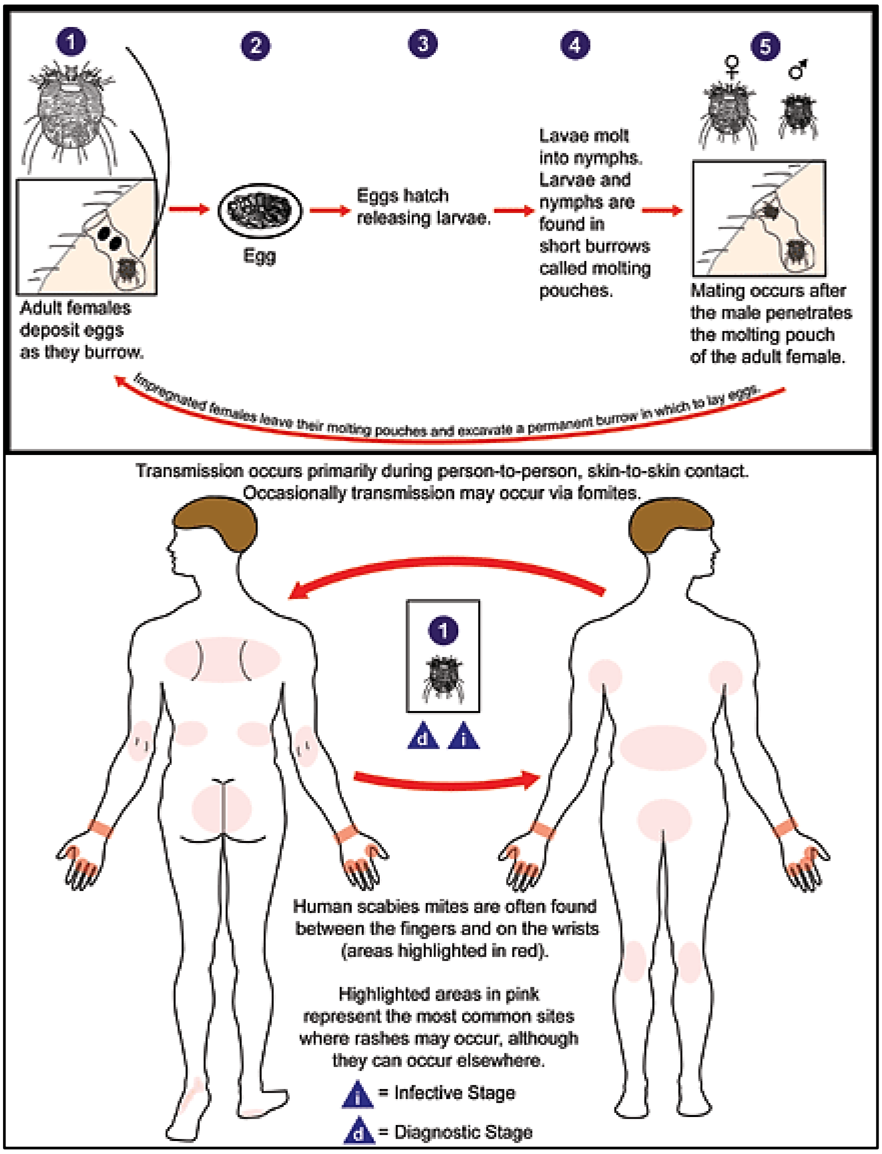


Fig 6: Life cycle of *Sarcoptes scabie*

Mating occurs after the active male penetrates the molting pouch of the adult female. Mating takes place only once and leaves the female fertile for the rest of her life. Impregnated females leave their molting pouches and wander on the surface of the skin until they find a suitable site for a permanent burrow. While on the skin's surface, mites hold onto the skin using sucker-like pulvilli attached to the two most anterior pairs of legs. When the impregnated female mite finds a suitable location, it begins to make its characteristic serpentine burrow, laying eggs in the process. After the impregnated female burrows into the skin, she remains there and continues to lengthen her burrow and lay eggs for the rest of her life (1-2 months). Under the most favorable of conditions, about 10% of her eggs eventually give rise to adult mites. Males are rarely seen; they make temporary shallow pits in the skin to feed until they locate a female's burrow and mate.

Types of scabies

There's only one type of mite that causes scabies infestation. This mite is called *Sarcoptes scabiei. However, these mites can cause several types of infestations.*

1. ***Typical scabies***

This infestation is the most common. It causes an itchy rash on the hands, wrists, and other common spots. However, it doesn't infest the scalp or face.

2. ***Nodular scabies***

This type of scabies may develop as itchy, raised bumps or lumps, especially in the genital areas, armpits, or groin.

3. ***Norwegian scabies***

Some people with scabies may develop another form of scabies known as Norwegian scabies, or crusted scabies. This is a more severe and extremely contagious type of scabies. People with crusted scabies develop thick crusts of skin that contain thousands of mites and eggs.

Crusted scabies usually develops in people with weakened immune systems. This includes people with HIV or AIDS, people who use steroids or certain medications (such as some for rheumatoid arthritis), or people who are undergoing chemotherapy.

The scabies mites can overpower the immune system more easily and multiply at a quicker rate. Crusted scabies spreads in the same way as normal scabies.

Mode of transmission of Scabies:

Transmission occurs primarily by the transfer of the impregnated females during person-to-person, skin-to-skin contact. Occasionally transmission may occur via fomites (e.g., bedding or clothing). Human scabies mites often are found between the fingers and on the wrists.

Common Symptoms

- ✓ The most common symptoms of scabies, itching and a skin rash, are caused by sensitization (a type of "allergic" reaction) to the proteins and faeces of the parasite. Severe itching (pruritus), especially at night, is the earliest and most common symptom of scabies. A pimple-like itchy (pruritic) "scabies rash" is also common.
- ✓ Itching and rash may affect much of the body or be limited to common sites such as: between the fingers, wrist, elbow, armpit, penis, nipple, waist, buttocks, and shoulder blades. The head, face, neck, palms, and soles often are involved in infants and very young children, but usually not adults and older children.
- ✓ Tiny burrows sometimes are seen on the skin; these are caused by the female scabies mite tunneling just beneath the surface of the skin. These burrows appear as tiny raised and crooked (serpiginous) grayish-white or skin-colored lines on the skin surface. Because mites are often few in number (only 10-15 mites per person), these burrows may be difficult to find.

Possible Complications

The intense itching of scabies leads to scratching that can lead to skin sores. The sores sometimes become infected with bacteria on the skin, such as Staphylococcus *aureus* or beta-hemolytic streptococci. Sometimes the bacterial skin infection can lead an inflammation of the kidneys called post-streptococcal glomerulonephritis.

Treatment

Often consists of medications that kill scabies mites and their eggs. Since scabies is so contagious, doctors will usually recommend treatment for an entire group of people who are in frequent contact with a person who has scabies.

Recognizing scabies bites and the distinctive red rash can help you find treatment faster.

Application of ointments, creams, and lotions can be applied directly to the skin. Oral medications are also available.

Your doctor will probably instruct you to apply the medicine at night when the mites are most active. You may need to treat all of your skin from the neck down. The medicine can be washed off the following morning.

Make sure you follow your doctor's instructions very carefully. You may need to repeat the topical treatment in seven days.

Some common medicines used to treat scabies include:

- 5 percent permethrin cream
- 25 percent benzyl benzoate lotion
- 10 percent sulfur ointment
- 10 percent crotamiton cream
- antihistamines, such as Benadryl (diphenhydramine) or pramoxine lotion to help control the itching
- An oral tablet called ivermectin (Stromectol) can be given to people who don't see an improvement in symptoms after initial treatment
- Sulfur is an ingredient used in several prescription scabies treatments. You can also purchase sulfur over the counter and use it as a soap, ointment, shampoo, or liquid to treat scabies.

Natural treatment of scabies

Common natural treatments for scabies include: Tea tree oil, Aloe vera, Capsaicin cream, Essential oils, Soaps

Prevention and Control

When a person is infested with scabies mites the first time, symptoms may not appear for up to two months after being infested. However, an infected person can transmit scabies, even if they do not have symptoms. Scabies usually is passed by direct, prolonged skin-to-skin contact with an infected person. However, a person with crusted (Norwegian) scabies can spread the infestation by brief skin-to-skin contact or by exposure to bedding, clothing, or even furniture that he/she has used.

Scabies is prevented by avoiding direct skin-to-skin contact with an infected person or with items such as clothing or bedding used by an infected person. Scabies treatment usually is recommended for members of the same household, particularly for those who have had prolonged skin-to-skin contact. All household members and other potentially exposed persons should be treated at the same time as the infested person to prevent possible re-exposure and reinfection. Bedding and clothing worn or used next to the skin anytime during the 3 days before treatment should be machine washed and dried using the hot water and hot dryer cycles or be dry-cleaned. Items that cannot be dry-cleaned or laundered can be disinfested by storing in a closed plastic bag for several days to a week. Scabies mites generally do not survive more than 2 to 3 days away from human skin. Children and adults usually can return to child care, school, or work the day after treatment.

Persons with crusted scabies and their close contacts, including household members, should be treated rapidly and aggressively to avoid outbreaks. Institutional outbreaks can be difficult to control and require a rapid, aggressive, and sustained response.

Rooms used by a patient with crusted scabies should be thoroughly cleaned and vacuumed after use. Environmental disinfestations using pesticide sprays or fogs generally is unnecessary and is discouraged.

Control of mites

- ✓ The primary mite *host* must be eliminated before successful control of *rodent or bird mites* can be achieved. Clues to the type of host that has invaded the house can be deduced by the time of year that the mite infestation occurs. Rodent infestations are possible at any time of year, though they seem to occur most frequently in the fall and winter. Bird problems are most common during the spring and summer.
- ✓ To seal homes against rodents all vents and electric service entry points should be tightly closed with rodent-proof metal hardware cloth, metal flashing, or copper wool. Entry points around chimneys and between loose shingles should also be checked. Doors and windows should seal tightly. House mice will enter structures near the ground, especially under poorly-sealed doors. Rodent proofing must include the smallest entry holes. Mice can enter a home through a hole as small as a dime; rats can enter through a hole as small as a quarter.
- ✓ *Bird infestations* are often first indicated by the sound of chirping coming from a chimney or soffit area. The same rules and materials used for rodent-proofing are effective in keeping birds out of the home. Special screening may be needed on chimneys to deny bird's access to chimney areas. Birds nesting in chimneys may also indicate the need for chimney maintenance and cleaning.
- ✓ Chickens and other fowl kept in sheds or coops attached to a home can also be a source of mites indoors.
- ✓ Pesticides can help suppress mite populations in the home, but must be used in combination with bird or rodent control. Several pesticides can be used indoors to treat mite problems. Sprays and aerosols containing synergized pyrethrins should kill mites immediately on contact, though the treatment will only remain effective for up to a few hours.
- ✓ Insecticide sprays containing permethrin or bifenthrin are effective against many mites and should retain their killing properties for several weeks. Read the label carefully before spraying to make sure these products allow application to living areas, attics and crawl spaces. Indoor sprays should be applied only to the bases of walls and other potential entry points, not to furniture or other surfaces where people come into direct contact.
- ✓ When a nest can be located, it's best to first treat the area around the nest (e.g., the soffit or vent from which a bird nest is removed) with a pesticide, or else dust the area with a desiccant dust, such as diatomaceous earth. This should reduce the risk

of live mites dispersing from the site and entering the indoor areas of the structure after the nest is removed.

- ✓ Long sleeves, gloves, and a tight-fitting dust mask are recommended when removing old bird or rodent nests to reduce the risk of exposure to ecto-parasites, like mites, and other pathogens.

Probable questions:

1. Discuss general morphology of mites.
2. Write short notes on Chigger.
3. What is the causative agent of scabies? Describe the life cycle of that agent.
4. Discuss the different types of scabies.
5. How mites population can be controlled?

Suggested readings:

1. Bernays, E.A. and Chapman, R.F. (). Host Selection by Phytophagous insects. Chapmanand Hall, New York, USA
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3. Hati, A.K. (2010). Medical Entomology. Allied Book Agency, Kolkata.
4. Lehane, M.J. (2005). The Biology of Blood Sucking Insects. 2nd Edn. Cambridge Univ Press.
5. Nation, J.L. Insect Physiology and Biochemistry. CRC Press, USA
6. Snodgrass, R.E. Principles of Insect Morphology. Cornell Univ. Press, USA
7. Wilson, E.O. The Insect Societies. Harvard Univ. Press, UK

UNIT X

Parasitic insects and Acarines: General remarks on ticks in relation to morphology, habitat, life cycle and diseases caused by them

Objective:

In this unit we will discuss about general remarks on ticks in relation to morphology, habitat, life cycle and diseases caused by them.

Introduction

Ticks are ectoparasites, living by hematophagy on the blood of mammals, birds, and sometimes reptiles and amphibians to complete their complex life cycles. Ticks are small arachnids, part of the order Parasitiformes. Along with mites, they constitute the subclass Acaria. The fossil record suggests ticks have been around at least 90 million years. There are over 800 species of ticks throughout the world, but only two families of ticks, *Ixodidae* (hard ticks) and *Argasidae* (soft ticks), are known to transmit diseases or illness to humans. Hard ticks have a scutum, or hard plate, on their back while soft ticks do not. Tick-borne diseases occur worldwide.

Systematic position:

Kingdom-Animalia
Phylum-Arthropoda
Class-Arachnida
Subclass-Acaria (Acari, Acarina, Acarida)
Order-Anactinotrichidea (= Parasitoformes)
Suborder-Ixodida (= Metastigmata)
Family-Ixodidae
Families
Ixodidae – hard ticks
Argasidae – soft ticks
Nuttalliellidae

<u>Tick facts</u>

- Ticks are scientifically classified as Arachnida (a classification that includes spiders). The fossil record suggests ticks have been around at least 90 million years.

- Most tick bites do not transmit harmful microbes.
- There are a variety of tick-borne diseases.
- There is a wide range of symptoms that usually develop days to weeks after the tick bite. The symptoms depend on the particular microbe that is transmitted.
- For all tick bites, local cleansing and antibiotic cream may be applied.
- There are safe and effective methods for the removal of all types of ticks.

Habit and Habitat of Ticks:

Ticks' importance as agents or vectors has long been recognized. In general, ticks are parasites of animals. Most species of vertebrates higher than fishes are subjected to attack by ticks, particularly mammals whose warm blood is highly attractive to ticks. They parasitize man and other domesticated mammals fortuitously.

The high potency of ticks in the spread of disease of man and animals are due to some factors like:

1. They are persistent blood suckers:

They attach firmly while feeding and cannot be dislodged easily. Most species have a wide range of host, thus ensuring a relatively certain source of blood.

2. Longevity:

Most species have a long life span, may be 5 years or more. It is helpful for them to carry the infection for several years.

3. High reproductive potential:

The reproductive potential is quite high. Some species may deposit as many as 18,000 eggs. Some have the power to regenerate lost parts.

General Morphology of Ticks:

Ticks are characterized by a leathery integument and larger size in comparison to mites. Body is segmented but without readily visible segments (Fig 1).

The body is divided into two regions:

- The capitulum (also referred to as gnathosoma)
- The body proper
- *Capitulum* is not the true head though it is commonly referred to as such. It projects antero-ventrally and bears the mouth parts and a basal chitinous

segment known as basis capitulum. The ring-like basis capitulum connects the capitulum to the body proper.

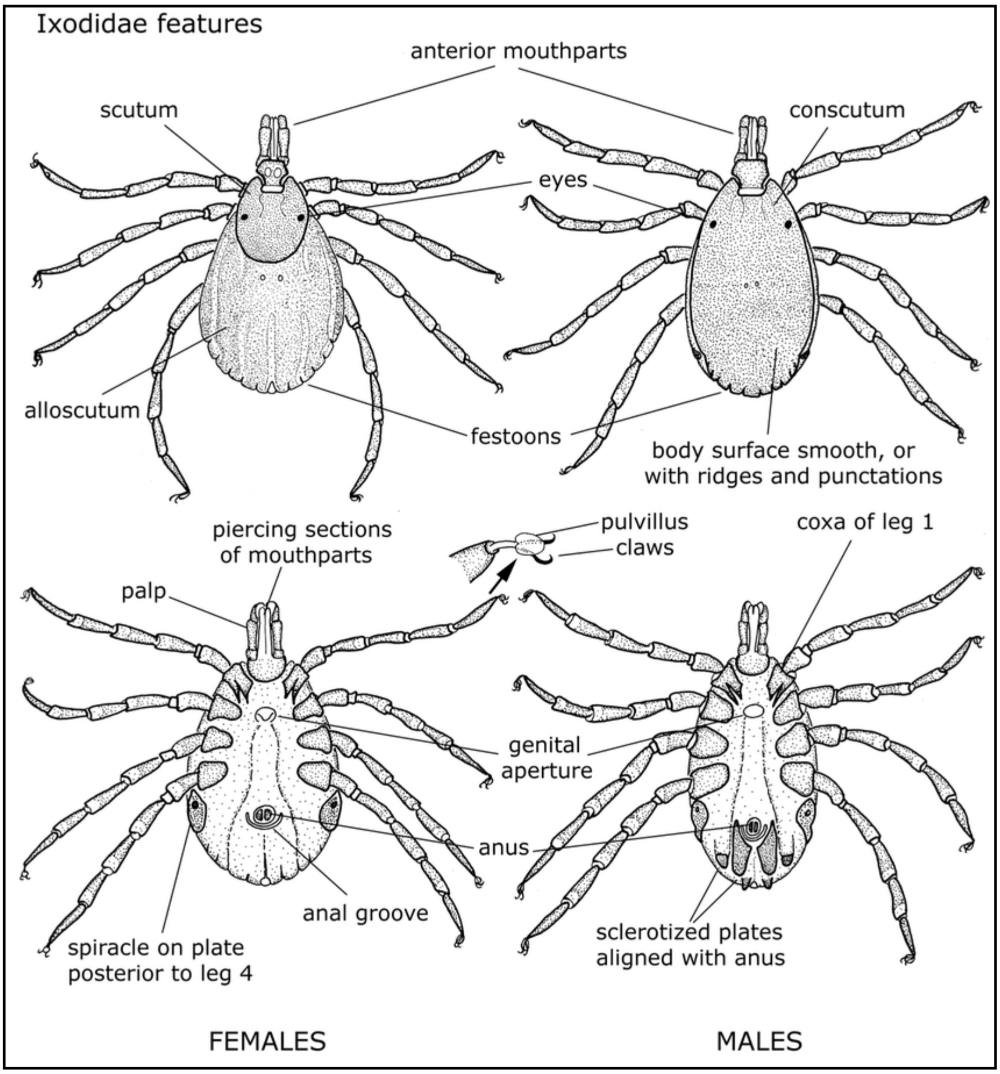

Fig 1: General morphology of Tick

The mouth parts include 3 types of structures:

- Ventral to the mouth is toothed, elongated hypo-stoma, its free end projects anteriorly (Fig 2).
- On the dorsal surface of hypo-stoma is located a pair of chelicerae, on each side of the mouth. The free terminal of each chelicera is forked (chelate), giving rise to a dorsal, fixed toothed digitus externus and lateral movable digitus internus.
- The chelicerae function as piercing, tearing and anchoring structure by means of which the host's integument is opened and the entire capitulum or at least the toothed hypostome is inserted into the host.

- A pair of palpi or pedipalpi arises from the anteroventral margin of the basis capitulum. These structures act as counter-anchors while the tick is attached to the host. The mouth-parts show characteristic differences among different species and also between male and female of the same species

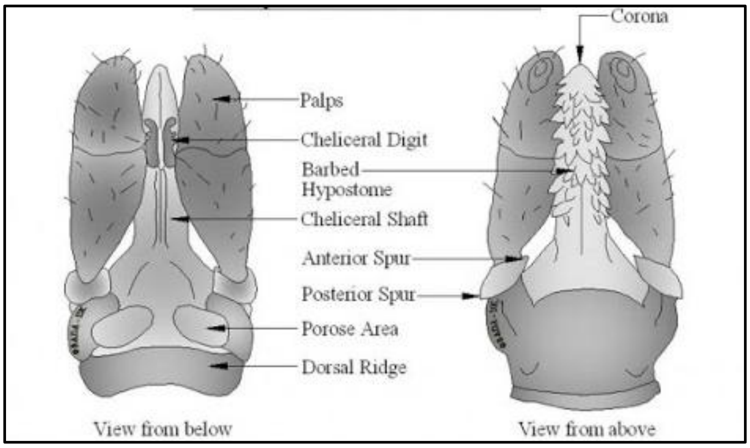

Fig 2: Mouthparts of tick

The *body proper* also shows differences among members of different families.

- It bears four pairs of legs; each is subdivided into six segments known as coxa, trochanter, femur, genu, tibia and tarsus. In some species, some of these units are fused. The legs characteristically terminate in a pair of claws on the tarsi.
- The genital orifice is located on the mid-ventro line between the first and second pairs of legs. The anus is also ventrally located, equidistant from the level of fourth pair of legs and the posterior margin of the body.
- On the basis of the difference present in body proper, two families are recognised in the order Ixodida; family Ixodidae and family Argasidae. Members of Ixodidae are commonly called **hard ticks** while those of argasidae are known as **soft ticks**. The morphological characteristics of these two families are discussed in Table 1.

Table 1: Differences between hard ticks and soft ticks

Characteristics	Argasidae	Ixodidae
MORPHOLOGY		
I. Capitulum		
Location	Sub terminal and so not visible on the dorsal aspect of adults Terminal and visible from dorsal aspect in larval stages	Terminal, visible from the dorsal aspect in all stages
Basis capitulum	Porose areas are absent	In female ticks the porose areas are seen on the dorsal

		aspect of basis capitulum
Pedipalps	Leg like, all 4 articles sub equal and flexible	Article IV recessed in a cavity in article III and the 1st article of the pedipalp is rigid
Chelicerae	Cheliceral sheath is smooth and distended	Cheliceral sheath is covered with teeth/ spines
II. Body		
Appearance of the surface	Leathery, mammillated or wrinkled	Smooth or superficially striated
Scutum	Absent	Present, entire dorsal surface covered in male ticks, half the surface covered in nymphs and larvae while in females only 1/3rd of the dorsal surface is covered by scutum
Festoons	Absent	Present
Eyes(when present)	Ventro-lateral on the supra coxal fold, 2 pairs, between 1st and 2nd and 2nd and 3rd pair of legs	Dorso-lateral in position, one pair is seen between the 1st and 2nd pair of legs
Spiracles	Small, seen between the 3rd and 4th coxae on ventral aspect	Seen on large spiracular plates posterior to the 4th coxae
Plates/grooves	Absent	Present
III. Legs		
Coxae	Unarmed	Armed, with internal and external spurs
Pulvilli	Rudimentary or absent	Present
IV. Sexual dimorphism		
	Not marked	Marked
BIOLOGICAL CHARACTERS		
Feeding habits	Intermittent feeders, rapid feeding in case of nymphs and adults, could also be slow in larval stages, cuticle expands to accommodate the blood meal but does not grow. They feed for few hours on the host and hence	Takes a single blood meal over a period of days. Slow feeder and hence attachment to the host becomes essential, they secrete attachment cement Cuticle grows to accommodate

	there is no formation of attachment cement	the large blood meal
Nymphal instars	Many	Only one
Mating	Off the host Single sex pheromone	On the host with the exception of *Ixodes* spp Multiple pheromone
Reproduction	200-300 eggs deposited by the female after each feeding Several batches of eggs are laid, so females feed and oviposit repeatedly Eggs emerge from opening on ventral side Eggs are waxed by the Gene's organ	Following engorgement the mated female deposits around 10,000-20,000 eggs per tick Only one batch of eggs and following oviposition the female tick shrivels and dies Eggs emerge from the dorsal aspect through a slit in between the scutum and basis capitulum Initially covered by the secretion of the accessory glands of the vagina followed by the Gene's organ
Host seeking behavior	Nidiculous, seen in protected areas such as the nest, cave, burrow etc of the host	Non nidiculous, seen in pastures and other areas where the host frequents, it ambushes the host
Seasonal activity	Active throughout the year	Active during the warmer months of the year
Habitats	Sheltered environments	Open environments
Life span	Long lived, infrequent blood meals, numerous nymphal stages and high resistance to starvation are the causes for the increase in life span	Not so long lived. Less resistant to starvation, only one nymphal stage and single blood meal

Life History of Ticks:

In the life cycle of all ticks, four basic stages could be recognized — egg, larva, nymph and adult. The life cycle of ticks requires 6 weeks to 3 years to complete in different species.

a. Eggs:

The gravid females drop onto the ground, where she deposits the eggs in the soil or humus. Hard ticks lay eggs in a few hundreds or even thousands, all at one time. The soft ticks lay eggs in batches of 20 to 100 over a long period. The eggs hatch in 1 to 3 weeks.

b. Larvae:

In the summer, tick eggs hatch into larvae. Once they reach this life stage, the thousands of tiny larvae that were once eggs are ready and waiting for their first host to pass by. A tick needs to feed on the blood of a host during each life stage in order to pass onto the next. Larvae are not infectious at their time of hatching. However at this stage, they seek smaller mammals as their first host, and one of the most common mammals they feed on is the white-footed mouse. After a blood meal, it drops off, and in course of time it moults to become a nymph. The duration of the larval stage may vary from 3 to 13 days. The larva of ticks possesses 3 pairs of legs.

c. Nymphs:

The nymph resembles the adult in having 4 pairs of legs, but it has no genital pore. The nymphs are all blood-suckers, and they attach themselves to suitable hosts for a blood meal. Members of Ixodidae have one nymphal instar, but argasids have as many as five.

Ticks, at the nymph stage, become the biggest concern during the spring as they begin to search for their next host when the warmer weather breaks. During the months of May, June, and July, nymphs will crawl up tall blades of grass and brush to reach their host. Ticks don't jump or fly. A nymph will wait for a desirable host to pass by and they'll latch onto it when they make contact. This is called questing.

d. Adults:

Adult ticks may live for a year or more. Soft ticks live longer than hard ticks. At the time of copulation, that occur on the host, the male ticks produce a spermatophore, which is placed under the genital operculum of the female.

Females usually require blood meal for egg production, although exceptions are there. Most opportunist ticks feed on a variety of hosts, while few are host-specific. Hard ticks can withstand a period of star-vation as long as 16 years.

The tick is called a one-host tick when all nymphal moulting through all instars occur on the same host, e.g., *Boophilus* sp. When the nymph drops off, moults to adult and attaches to another host, the tick is said a two-host tick. Most ixodids are three-host ticks whereas argasids with their multiple nymphal stages are many-host ticks. Use of such a series of hosts actually increases the opportunities for transmission of pathogens.

Tick Borne diseases:

Major tick-borne diseases include:

➢ ***Bacteria***

- **Lyme disease or Borreliosis**

  Organism: *Borrelia burgdorferi*

  Vector: deer tick (*Ixodes scapularis* (=*I. dammini*), *I. pacificus*, *I. ricinus* (Europe), *I. persulcatus* (Asia))

  Endemic to: North America and Eurasia

  Symptoms: Fever, arthritis, neuroborreliosis, cranial nerve palsy, carditis, fatigue, and influenza-like illness.

  Treatment: Antibiotics (Doxycycline in non-pregnant adults, Amoxicillin in pregnant adults and children)

  Mode of transmission: Ticks can acquire *B burgdorferi* from feeding on an infected animal host during any of the three life-cycle stages. Unless the tick has fed on an infected host before feeding on a person, infection cannot result from that tick bite. Even if a tick that has previously fed on an infected animal and then feeds on an infected animal, the animal may not acquire the infection. Mice do not appear to develop Lyme disease, but they do carry the bacteria. They may be considered infested rather than infected. Deer also are incompetent hosts for *Borrelia*. Ticks carry *B burgdorferi* organisms in their midgut. The bacteria are introduced into the skin by a bite from an infected tick, and disease is transmitted to humans as the spirochete is translocated from the gut to the salivary glands and then to the person at the site of the bite

- **Relapsing fever** (Tick-borne relapsing fever, different from Lyme disease due to different *Borrelia* species and ticks)

  Organisms: *Borrelia* species Such as *Borrelia hermsii*, *Borrelia parkeri*, *Borrelia duttoni*, *Borrelia miyamotoi*

  Vector: *Ornithodoros* species [**Reservoir** - *Ornithodoros* ticks are considered the best reservoir of TBRF *Borrelia* for several reasons: they have an extremely long life span without blood feeding; they have the capacity to harbour TBRF *Borrelia* for several years; they are able to transmit TBRF *Borrelia* from tick to tick through trans-stadial, trans-ovarial and venereal modes; and because of hyper parasitism. Numerous vertebrates have been reported to be naturally infected by TBRF *Borrelia*, but few studies have tested their role as reservoirs. Because of their endophilic characteristics, *Ornithodoros* ticks commonly parasitize and infect small mammals, birds, reptiles or bats living in their underground habitat.]

Regions: Primarily in Africa, Spain, Saudi Arabia, Asia in and certain areas of Canada and the western United States

Symptoms: Relapsing fever typically presents as recurring high fevers, flu like symptoms, headaches, and muscular pain, with less common symptoms including rigors, joint pain, cough, sore throat, painful urination, and rash.

Treatment: antibiotics are the treatment for relapsing fever, with doxycycline, tetracycline, or erythromycin being the treatment of choice.

Mode of transmission: Tick borne relapsing fever is strictly transmitted by *Ornithodoros* ticks that are haematophagous at all growing stages. *Ornithodoros* ticks attach to their hosts for less than one hour, except for some larvae that can stay 1–2 days. During feeding, some Ornithodoros ticks (e.g., *O. sonrai*) produce local analgesia so that the tick bites are not noticed. Vertebrates and humans become infected through contamination of the feeding site by salivary and/or coxal secretions during the blood meals. Non-treated humans are supposed to be asymptomatic carriers over several years with resurgence of the pathogen and infectiousness during relapses. The persistence of spirochaetes in other vertebrates is quite unknown. Ticks are infected by TBRF during a blood meal on a spirochaetaemic vertebrate (rodent). *Borrelia* spread in all tissues, including ovaries (responsible for trans-ovarial transmission), salivary glands and excretory organs. Ticks are able to maintain TBRF Borrelia during their whole life span (5–10 years).

- **Typhus**

Organism: *Rickettsia prowazekii [Rickettsia prowazekii* causes epidemic typhus. *Rickettsia typhi* and, occasionally, *R. felis* cause endemic typhus and are transmitted to humans by vectors such as lice (mainly epidemic) and fleas (mainly endemic)].

Vector: Lice, fleas

Risk factors include visiting or living in areas where rats, mice, and other animals have high populations (for example, disaster areas, poverty-stricken areas, refugee camps, jails) where vectors such as fleas and lice can carry the bacteria from the animals to infect humans.

Symptoms: Typhus is a vector-borne bacterial disease; there are two types termed endemic and epidemic.

Endemic typhus symptoms can include rash that begins on the body trunk and spreads, high fever, nausea, malaise, diarrhoea, and vomiting.

Epidemic typhus has similar but more severe symptoms, including bleeding into the skin, delirium, hypotension, and death.

Treatment:

Antibiotics e.g., azithromycin , doxycycline, tetracycline or chloramphenicolare used to treat endemic and epidemic typhus.

Good hygiene and clean living conditions that reduce or eliminate exposure to rats, mice, and other animals and the vectors that they carry (lice, fleas) can prevent or reduce one's risk for both types of typhus.

There is no commercially available vaccine against either endemic or epidemic typhus.

- **Rocky Mountain Spotted Fever**

Organism: *Rickettsia rickettsii*

Vector: wood tick (*Dermacentor variabilis*), *D. andersoni*

Region (US): East, South West

Vector: *Amblyomma cajennense*

Region (Brazil): São Paulo, Rio de Janeiro, Minas Gerais.

Symptoms: Fever, headache, altered mental status, myalgia, and rash.

Treatment: Antibiotic therapy, typically consisting of doxycycline or tetracycline.

Mode of transmission: Ticks are the natural hosts of *R. rickettsii*, serving both as reservoirs and as vectors. The two major vectors of *R. rickettsii* in the United States are the American Dog tick (*Dermacentor variabilis*) and the Rocky Mountain Wood tick (*Dermacentor andersoni*).Ticks may obtain the pathogen by feeding on small mammals such as chipmunks and squirrels functioning as reservoirs for *R. rickettsii*. During feeding of larval and nymphal stages on these animals, ticks are most often infected with *R. rickettsii*. Once infected, ticks may spread the infectious agent trans-stadially among their own population, or trans-ovarially from the female tick to its offspring. The latter seems to be the primary way by which *R. rickettsii* propagates in nature. Dogs and humans may also function as reservoirs, but probably constitute incidental hosts and display clinical signs of disease. Ticks transmit the *rickettsiae* to all vertebrates primarily through their saliva during feeding. It usually takes several (5 to 20) hours of attachment and feeding before the *rickettsiae* are transmitted to the host. Less commonly, infections may occur following exposure to crushed tick tissues, fluids, or tick faeces.

- **<u>Tularaemia</u>**

Organism: *Francisellatularensis*, *A. americanum*

Vector: *<u>D. andersoni</u>*, *<u>D. variabilis</u>*

Region (US): Southeast, South-Central, West, Widespread

Symptoms: Tularaemia causes fever, fatigue, aches and headache. Swollen lymph nodes are common. A sore may form at the site of inoculation. The organism may spread widely, causing major organs to fail. <u>Pneumonia</u> is common after inhalation but may also occur when the organism spreads throughout the body. If untreated, tularaemia is often fatal. With treatment, death is rare.

Treatment: Tularaemia is treated with intramuscular streptomycin or intravenous gentamicin. Oral medications are less reliable and are not currently recommended for significant disease.

Mode of transmission: Tularaemia affects animals and humans. Humans acquire tularaemia when they come into contact with infected animals or are bitten by insects that feed on infected animals. This disease may be spread through <u>inhalation</u> of dried animal matter, eating undercooked game, skinning or dressing killed animals, or drinking water contaminated with animal carcasses. It is not transferred from person to person.

➢ Viruses

- **<u>Tick-borne meningo-encephalitis</u>**

Organism: <u>TBEV</u> aka FSME virus, a <u>flavivirus</u> from family <u>Flaviviridae</u>

Vector: deer tick (*<u>Ixodes scapularis</u>*), *<u>Ixodes ricinus</u>* (Europe), *<u>Ixodes persulcatus</u>* (Russia + Asia))

Endemic to: Europe and Northern Asia

- **<u>Colorado tick fever</u>**

Organism: Colorado Tick Fever virus (CTF), a <u>coltivirus</u> from <u>Reoviridae</u>

Vector: *<u>Dermacentor andersoni</u>*

Region: US (West)

- **<u>Crimean-Congo hemorrhagic fever</u>**

Organism: CCHF virus, a nairovirus, from Bunyaviridae

Vector: *Hyalomma marginatum*, *Rhipicephalus* bursa

Region: Southern part of Asia, Northern Africa, Southern Europe

- **Severe Febrile Illness**

Organism: Heartland virus, a phlebovirus, from Bunyaviridae

Vector*:* Lone Star Tick *(Amblyomma americanum)*

Region*:* Missouri and Tennessee, United States

➢ Protozoa

- **Babesiosis**

Organism: *Babesia microti*, *B. equi*

Vector: *Rhipicephalus sanguineus* , *Dermacentor* ticks, *Ixodes scapularis*

Region (US): Northeast West Coast

Mode of transmission: *Rhipicephalus sanguineus* is the primary vector for *Babesia* in warmer regions worldwide, like in Southern Europe, Southern USA, Australia and Latin America. In Western and Central Europe, the main vectors for *Babesia* are *Dermacentor* ticks, esp. *Dermacentor reticulatus*. Transmission within the tick is both trans-stadial (infection at any stage for *Rhipicephalus* and the next stage being infectious) and trans-ovarial (females of *Rhipicephalus* and *Dermacentor* may transfer infection to the next generation through eggs). As a consequence, nymphs and adults of *Rhipicephalus* can be infectious when larvae or nymphs have fed on an infected dog (trans-stadial), whereas adults of *Dermacentor* will only be infectious from the previous infected tick generation (trans-ovarial), because larvae and nymphs of *Dermacentor* do not feed on dogs.

Babesia microti parasites live in the gut of the black-legged or deer tick (*Ixodes scapularis*). The tick attaches to the body of white-footed mice and other small mammals, transmitting the parasite to the rodents' blood.After the tick has eaten its meal of the animal's blood, it falls off and waits to be picked up by another animal. The white-tailed deer is a common carrier of the deer tick. The deer itself isn't infected.After falling off the deer, the tick will typically rest on a blade of grass, a low branch, or leaf litter. If you brush up against it, it can attach to your shoe, sock, or other piece of clothing. The tick then climbs upward, seeking a patch of open skin. Human probably won't feel the tick bite, and you may not even see it. That's because most human infections are spread during spring and summer by ticks in the nymph stage. During this stage, the ticks are about the size and colour of a poppy seed.

Symptoms: High fever, chills, muscle or joint aches, and fatigue. Less common symptoms include - severe headache, abdominal pain, nausea, skin bruising, yellowing of your skin and eyes, mood changes

- **Cytauxzoonosis**

  Organism: *C. felis*

  Vector: *D. variabilis* (American Dog Tick)

  Region (US): South, Southeast

Probable questions:

1. Discuss the general morphology of ticks?
2. Write short note on tick's mouthparts?
3. Differentiate between hard ticks and soft ticks.
4. Describe the life cycle of tick with proper diagram.
5. Write down the mode of transmission of tick born bacterial disease.
6. Write down the symptoms, treatment and mode of transmission and causative agent of tick born bacterial disease.
7. Discuss the mode of transmission of relapsing fever.

Suggested readings:

1. Bernays, E.A. and Chapman, R.F. Host Selection by Phytophagous insects. Chapmanand Hall, New York, USA
2. Gullan, P.J. and Cranston, P.S. The Insects: An Outline of Entomology. Wiley Blackwell.
3. Hati, A.K. (2010). Medical Entomology. Allied Book Agency, Kolkata.
4. Lehane, M.J. (2005). The Biology of Blood Sucking Insects. 2nd Edn. Cambridge Univ Press.
5. Nation, J.L. Insect Physiology and Biochemistry. CRC Press, USA
6. Snodgrass, R.E. Principles of Insect Morphology. Cornell Univ. Press, USA
7. Wilson, E.O. The Insect Societies. Harvard Univ. Press, UK

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<tr><td>XVII</td><td>Landscape Ecology:
a) Theories in landscape ecology. Hierarchy theory and the structure of the landscape, Percolation theory, The systems source sink,
b) Scale and landscape, Scaling the landscape, Change of scale perception. Importance of parameters at different scales,</td><td></td></tr>
<tr><td>XVIII</td><td>Landscape Ecology:
c) Processes in the landscape: Disturbance, Fragmentation, Landscape connectivity, Corridors,
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	XX	Organic evolution: concept and evidences (comparative anatomy, embryology, biogeography, palaeontology, genetics, biochemistry and physiology).		
	Total counseling session 18hrs.			

UNIT XI

Levels of species diversity and relationship; geographic distribution of biological diversity; biological hotspots; measuring biodiversity; interrelationship between diversity measures; pattern of local and regional biodiversity

Objective:

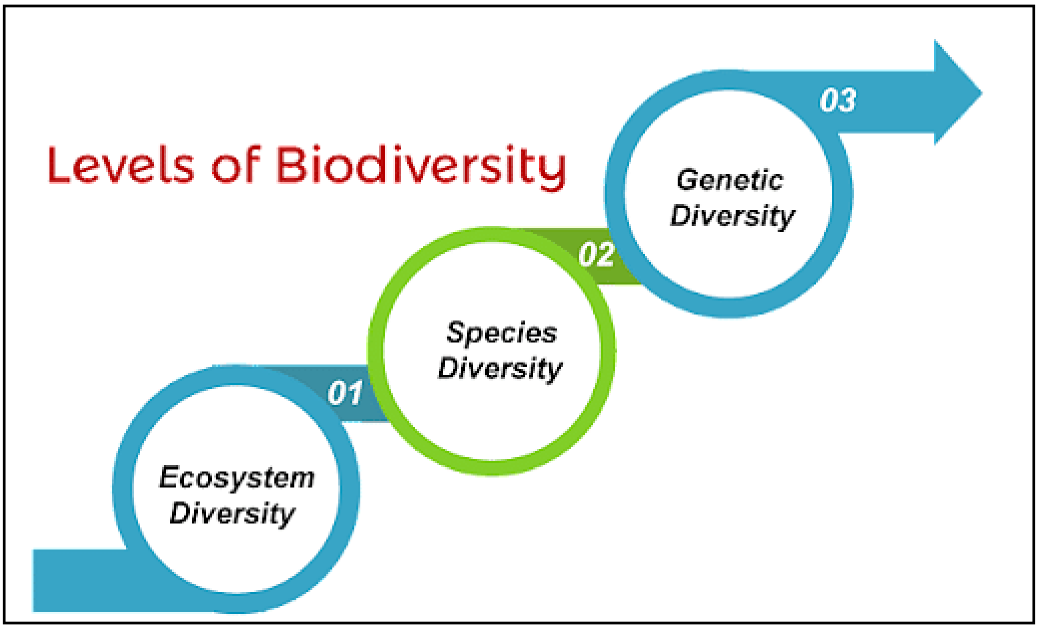
In this unit we will discuss different topics of biodiversity. This unit includes the discussion about levels of species diversity and relationship; geographic distribution of biological diversity; biological hotspots; measuring biodiversity; interrelationship between diversity measures; pattern of local and regional biodiversity.

Introduction:

The term **"Biodiversity"** refers to the heterogeneity present in the world or a habitat, ranging from macromolecules within the cells to biomes. Biodiversity comprises:

- **Species diversity:** Variety of species and abundance of species
- **Genetic diversity:** Genetic variability present within the species
- **Ecological diversity:** Ecosystem variety present within a geographical area

Scientists often speak of three levels of diversity: **species, genetic, and ecosystem diversity**. In fact, these levels cannot be separated. Each is important, interacting with and influencing others.



Biodiversity - Levels

Genetic Diversity

- Genetic diversity describes the variety of unique genetic features found in a species.
- There would be many individuals with a wide range of diverse characteristics in a species with significant genetic diversity.
- For a population to adapt to changing surroundings, genetic diversity is essential.
- A population's capacity to adjust to changes will be lowered if a highly selected and low diversity strain, such as fish populations raised for aquaculture, is introduced.
- Those individuals tend to survive to have offspring with that allele (a variant of a given gene).
- The success of these people will allow the population to continue for long generations.

Species Diversity

- The number of different species found in a given area is referred to as species diversity.
- In nature, species do not interbreed because they differ genetically from one another.
- However, closely related species share a lot of their inherited traits.
- For example, 98.4% of the genes in humans and chimps are similar. It is the proportion of a species' total population to all the species' combined total number of organisms in a given biome.
- "One" denotes the presence of just one species, while "zero" would indicate infinite diversity.

Ecosystem / Community Diversity

- Community diversity, also called ecosystem diversity, defines a community of interacting groups from different species living in a single habitat.
- The combination of a region's climate, vegetation, and terrain makes up a habitat. There are many different types of habitats on the earth.
- Examples of habitats in an environment include corals, grasslands, wetlands, deserts, mangroves, and tropical rain forests.
- Every species adjusts to a specific type of environment.
- The species that are most adapted to a changing environment become more prevalent.

- As a result, the ecosystem's features influence the variety or diversity of species present.

What is Species Diversity?

- The number of different species found in a given area is referred to as the species diversity.
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- **"One"** denotes the presence of just one species, while **"zero"** would indicate infinite diversity.

Components of Species Diversity

- When all of the species present are equally abundant in the area, diversity is greatest. Species diversity is made up of two components:
    - **Species richness:** It refers to the number of different species found in an ecosystem. Tropical areas have a higher species richness because the environment supports a large number of species.
    - **Species evenness:** The relative abundance of individuals within each species. If the number of individuals within a species remains relatively constant across communities, the species is said to have high evenness; if the number of individuals varies from species to species, the species is said to have low evenness. Greater specific diversity results from high evenness.
- In an ecosystem, it is possible to have high species richness but low species evenness. For example:
    - There may be a large number of different species (high species richness) in a forest, but only a few members of each species (low species evenness).
    - A forest may have only a few plant species (low species richness), but many of each species (high species evenness).
- The diversity of species varies by geographical location, with the tropics having the highest diversity and decreasing as we move towards the poles.
- Tropical rainforests, coral reefs, and the ocean bottom zone have the most species.

- The richness of species increases as the explored area expands.

Importance of Species Diversity

In a healthy ecosystem, diverse and balanced number of species exists to maintain the balance of an ecosystem. In an ecosystem, all the species depend on each other directly or indirectly. So to make a more efficient, productive and sustainable ecosystem, it is important to maintain high species diversity.

- More diverse ecosystem tend to be more productive. E.g. the ecosystem with a great variety of producer species will produce large biomass to support a greater variety of consumer species
- Greater species richness and productivity makes an ecosystem more sustainable and stable
- More diverse the ecosystem, greater is the ability to withstand environmental stresses like drought or invasive infestations
- Species richness makes an ecosystem able to respond to any catastrophe
- In Species-rich communities, each species can use a different portion of resources available as per their requirement. E.g. plants with smaller roots can absorb water and minerals from shallow soil and plants with deeper roots can tap deeper soil
- Rich diversity is important for the survival of mankind
- Healthy biodiversity has innumerable benefits like nutrients storage and recycling, soil formation and protection from erosion, absorption of harmful gases, climate stability
- Humans get lots of product from nature like fruits, cereals, meat, wood, fibre, raisin, dyes, medicine, antibiotics, etc.
- Amazon forest is estimated to produce 20 percent of total oxygen in the earth's atmosphere through photosynthesis
- Pollinators, symbiotic relationships, decomposers, each species perform a unique role, which is irreplaceable
- Diversity in large numbers help in large scale interaction among organisms such as in the food web
- In the nitrogen cycle, bacteria, plants have a crucial relationship, earthworms contribute to soil fertility
- Apart from these, there are other benefits such as recreation and tourism, education and research

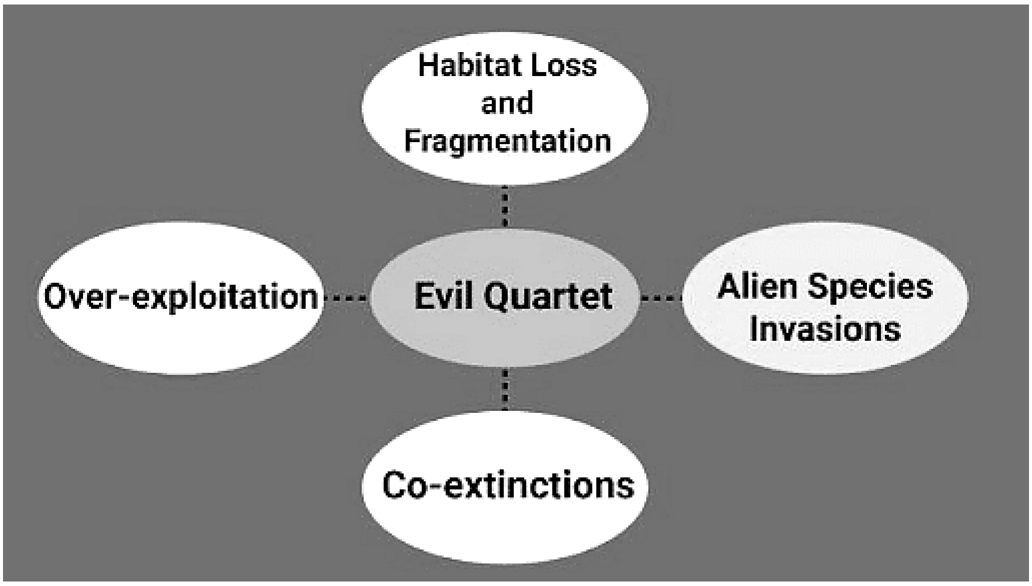
Examples of the ecosystem with high Species Diversity

I. **Tropical Rainforests:** They contain half of the world's species. There are about 5-10 million insect species present. 40% of the world's 2,75,000 species of flowering plants are present in the tropical regions. 30% of total bird species are present in tropical forests. The species richness of tropical forests is mostly due to relatively constant environmental conditions.

II. **Coral Reefs:** Colonies of tiny coral animals build the large coral reefs ecosystem. The clarity of the water in the coral reef systems allow the sunlight to penetrate deep, resulting in the high level of photosynthesis in the algae present inside the coral. Adaptation to various disturbances and niche specialisation gives rise to species richness.

The Great Barrier Reef of Australia is the world's largest coral reef with an area of 349,000Km^2**.** It contains about 400 species of coral, 1500 species of fish, 4000 species of molluscs and 6 species of turtles. It provides a breeding site for around 250 species of birds. It covers only 0.1% of the ocean but has about 8% of the world's fish species. There are thousands of species which are yet to be discovered and described.

Threats to species diversity



The world is facing an accelerated rate of extinction of species largely due to human activities. The four major causes of loss of diversity are known as **"The Evil Quartet".**

These are:

- **Habitat Loss and Fragmentation:** Due to pollution, urbanisation and various other human activities, habitat loss and fragmentation is a major cause of loss in species diversity and driving plants and animals extinct. E.g.

- Amazon rainforest (lungs of the planet), which is a house to millions of species are being cut and cleared for various purposes
- Tropical rainforest, which once covered 14 per cent of landmass, is no more than 6 percent now

Over Exploitation: Over-exploitation of natural resources leads to the extinction of many species. E.g. Steller's sea cow, the passenger pigeon, many marine fishes are overharvested

Alien species invasions: When alien species are introduced deliberately or unintentionally, some of them become invasive, leading to the extinction of indigenous species. E.g.

- Extinction of cichlid fish in Lake Victoria due to the introduction of the Nile perch
- Illegal introduction of the African catfish is a threat to indigenous catfishes in rivers

Co-extinctions: When a species becomes extinct, the species that are associated with it also becomes extinct. E.g.

- When a host fish goes extinct, the parasite also goes extinct
- Mutualism like a plant-pollinator, where extinction of one species leads to the extinction of other species too

Biodiversity - Conservation

- Every species contributes significantly to the environment. Diversity needs to be preserved because if it goes extinct, it is irreplaceable.
- **In-situ Conservation:** In-situ conservation refers to the protection of biodiversity-rich areas like biosphere reserves, national parks, and sanctuaries; preserving the Sunderbans for numerous threatened species, including the olive ridley sea turtle, mangrove species, and the royal Bengal tiger.
    - Hotspots for biodiversity have been found that are rich in species.
    - Globally, 34 hotspots have been identified; for instance, our country's Western Ghats, Sri Lanka, Indo-Burma, and Himalaya regions have significant biodiversity.
    - In many civilizations, wildlife and trees are given complete protection, such as in sacred groves.
- **Ex-situ Conservation:** Ex-situ conversations take place when endangered and threatened species are located, removed, and preserved in designated areas like botanical gardens, wildlife safaris, etc. with full protection.

- Cryopreservation procedures are used to preserve the gametes of endangered species.
- The seed bank houses the seeds of plants with significant economic value.

Geographic Distribution of Biological Diversity

Biomes of the World :

There are manly 8 biomes in the world which are described below:

Biome # 1. Tundra:

The literal meaning of word Tundra is north of the timberline. The tundra extends above 60°N latitude. It is almost treeless plain in the far northern parts of Asia, Europe and North America. A tundra consists of plains characterised by snow, ice and frozen soil most of the year. The permanent frozen soil of tundra is called permafrost.

Winters are very long on the tundra with little daylight. In contrast summers are short but there are many daylight hours. Precipitation is low, amounting to only 25 cm or less per year, because cold air can hold relatively little moisture.

The ground is soggy in the summer because moisture cannot soak into the permanently frozen ground. Ponds, small lakes and marshes are abundant due to the nearly flat terrain.

There are no upright trees on the tundra. Only trees such as dwarf willows and birches, which grow low to the ground, can escape the drying effect of the wind which upright trees would experience. This biome consists mainly of mosses, grasses, sedges, lichens and some shrubs. Seasonal thawing of the frozen soil occurs only up-to a few centimetres depth, which permits the growth of shallow rooted plants.

Fig. 12.20. Tundra biome.

Carbon, arctic hare and musk ox are important herbivores of tundra biome. Some important carnivores that prey on the herbivores are the arctic fox, arctic wolf, bobcat and snowy owl. Polar bears live along coastal areas, and prey on seals.

Because of the severe winters, many of the animals are migratory and move from one region to another with the change in seasons. Many shorebirds and water fowls, such as ducks and geese, nest on the tundra during the summer but migrate south for the winter. The tundra make a very delicate ecosystem, and may be recovered from any disturbance very slowly.

Biome # 2. Northern Conifer Forest:

The northern coniferous forest or taiga is a 1300-1450 km wide band south of the tundra. This extends as an east-west band across North America, Europe and Asia. This area also has long, cold winters, but summer temperatures may reach 10-12°C, and the summer and the growing season are longer than in the tundra. Precipitation is higher than in the tundra, ranging from 10 to 35 cm annually.

The moisture is the combined result of summer rains and winter snows. Lakes, ponds and bogs are abundant. The duration of growing period of plants is only about 150 days. Since five physical conditions are variable, the organisms are resistant to fluctuations of temperature.

The taiga makes really a northern forest of coniferous trees such as spruce, fir, pine, cedar and hemlock. In disturbed areas, deciduous trees such as birch, willow and poplar are abundant. In certain areas the trees are so dense that little light may reach the floor of the forest. Vines, maple and spring wild flowers are common. Mosses and ferns also grow in moist areas.

The common smaller mammals are herbivores, such as squirrels, snowshoe hare, and predatory martens. Important migratory herbivores include moose, elk, deer and carbon. Moose and carbon migrate to the taiga for winters and to the tundra for summers.

Important predators are the timber wolf, grizzly bear, black bear, bobcat and wolverine. Many insects are found during the warmer months. Migratory shore birds and waterfowls are abundant during summer months.

Fig. 18.22. Temperate deciduous forest biome.

Biome # 3. Temperate Deciduous Forests:

The deciduous forests are found in the temperate regions of north central Europe, east Asia and the eastern United States, that is, south of the taiga in the Northern Hemisphere. Such forests occur in regions having hot summers, cold winter, rich soil and abundant rain. Annual rainfall is typically around 100 cm per year.

Common deciduous trees are the hardwoods such as beech, maple, oak, hickory and walnut. They are broad-leaved trees. The trees shed their leaves in the late fall so the biome has an entirely different appearance in the winter than in the summer.

The fallen leaves provide food for a large variety of consumer and decomposer populations, such as millipedes, snails and fungi living in or on the soil. The temperate deciduous forest produces flowers, fruits and seeds of many types which provide a variety of food for animals.

The common herbivores of this biome are deer, chipmunks, squirrels, rabbits and beavers. Tree- dwelling birds are abundant in number and diversity. Important predators are—black bears, bobcats, and foxes. Predatory birds are also found, such as hawks, owls and eagles. The coldblooded or ectothermic animals, such as snakes, lizards, frogs, and salamanders are also common.

The temperate deciduous forest makes a very complex biome. Many changes take place during the year, and a large variety of species inhabit the soil, trees and air.

Fig. 12.23. Stratification in a tropical rain forest strata : 1. Tallest trees; II. dense canopy of trees ; III. short trees ; IV. shrubs ; V. herbs and decaying.

Biome # 4. Tropical Rain Forest:

This biome is situated in the equatorial regions having the annual rainfall more than 140 cm. However, the tropical rain forest makes an important biome across the earth as a whole. This biome is found in Central America, the Amazon Basin, Orinocon Basin of South America, Central Africa, India and Southeast Asia.

Tropical rain forests have high rainfall, high temperature all year, and a great variety of vegetation. Plant life is highly diverse reaching up-to a framework of 200 species of trees per hectare. The warm, humid climate supports broad- leaved evergreen plants showing peculiar stratification into an upper storey and two or three understoreys.

The tallest trees make an open canopy, but the understoreyed plants block most of the light from the jungle floor. The climbers and lianas reach the highest level of the trees in search of light.

An enormous variety of animals lives in the rain forest, such as insects, lizards, snakes, monkeys and colorful birds. The ant eaters, bats, large carnivorous animals, and a variety of fish in the rivers are quite common. About 70-80 per cent of the known insects are found in tropical rain forests. Such rich animal diversity is linked to plant-animal interaction for pollination and dispersal of fruits and seeds.

Biome # 5. Chapparal:

This biome is also known as mediterranian scrub forest. This is marked by limited winter rain followed by drought in the rest of the year. The temperature is moderate under the influence of cool, moist air of the oceans. The biome extends along the mediterranian.

Pacific coast of North America, Chile, South Africa and South Australia. This biome has broad-leaved evergreen vegetation. The vegetation is generally made up of fire resistant resinous plants anddrought-adapted animals. Bush fires are very common in this biome.

Biome # 6. Tropical Savannah:

The savannahs are warm climate plants characterized by coarse grass and scattered trees on the margins of tropics having seasonal rainfall. Primarily they are situated in South America, Africa and Australia. However, there is no savannah vegetation in India. The average total rainfall in such regions is 100 to 150 cm. There is alternation of wet and dry seasons.

Plants and animals are drought tolerant and do not have much diversity. The animal life of tropical savannah biome consists of hoofed herbivorous species, such as giraffe, zebra, elephant, rhinoceros and several kinds of antelope. Kangaroos are found in the savannahs of Australia.

Biome # 7. Grassland:

Some grasslands occur in temperate areas of the earth and some occur in tropical regions. Temperate grasslands usually possess deep, rich soil. They have hot summers cold winters and irregular rainfall. Often they are characterized by high winds. The main grasslands include the prairies of Canada and U.S.A., the pampas of South America, the steppes of Europe and Asia, and the veldts of Africa.

The dominant plant species comprise short and tall grasses. In tall-grasses prairies in the United States, important grasses are tall bluestem, Indian grass and slough grass. Short-grass prairies generally have blue grama grass, mesquite grass and bluegrass. Many grasses have long, well- developed root systems which enable them to survive limited rainfall and the effects of fire.

Fig. 12.24. Grassland biome.

The main animals of this biome are-the prong-horned antelopes, bison, wild horse, jack rabbit, ground squirrel and prairie dogs. Larks, the burrowing owl and badgers are also found. Important grassland predators include coyotes, foxes, hawks and snakes.

Biome # 8. Desert:

The desert biome is characterised by its very low rainfall, which is usually 25 cm per year or less. Most of this limited moisture comes as short, hard showers. Primarily the deserts of the world are located in the south-west U.S.A., Mexico, Chile, Peru, North Africa (Sahara desert), Asia (Tibet Gobi Thar) and central Western Australia. Deserts generally have hot days and cold nights, and they often have high winds.

The reason for the difference of temperature between day and night is due to the lack of water vapour in the air. Deserts are characterised by scanty flora and fauna. Desert organisms must meet some initial requirements if they are to survive. The plants must be able to obtain and conserve water.

In order to meet these requirements, many adaptations have been made by desert plants. Such adaptations are—reduced leaf surface area, which reduces evaporation from the plants, loss of leaves during long dry spell; small hairs on the leaf surfaces, and the ability to store large amount of water. The examples of important desert plants are—yuccas, acacias, euphorbias, cacti, many other succulents and hardy grasses. Many of the small plants are annuals.

Animals also must meet the requirements of heat, cold and limited water. Many desert animals are nocturnal in habit, and are active mainly at night. Many reptiles and small mammals burrow to get away from the intense heat of midday. The other common desert animals are the herbivorous kangaroo, rat, ground squirrel, and jack rabbit.

Fig. 12.25. Desert biome.

The important predators are—coyotes, badgers, kit fox, eagles, hawks, falcons and owls. Ants, locusts, wasps, scorpions, spiders, insect-eating birds, such as swifts and swallows, seed-eating quails,doves and various cats are other common desert animals.

Biological Hotspots

According to Conservation International, a region must fulfill the following two criteria to qualify as a hotspot:

1. The region should have at least 1500 species of vascular plants i.e., it should have a high degree of endemism.
2. It must contain 30% (or less) of its original habitat, i.e. it must be threatened.

Following the criteria must for an area to be declared as Biodiversity Hotspot, there are **major four biodiversity hotspots in India**:

1. The Himalayas
2. Indo-Burma Region
3. The Western Ghats
4. Sundaland

I. The Himalayas

Considered the highest in the world, the Himalayas (overall) comprises North-East India, Bhutan, Central and Eastern parts of Nepal. This region (NE Himalayas) holds a record of having 163 endangered species which includes the Wild Asian Water Buffalo, One-horned Rhino; and as many as 10,000 plant species, of which 3160 are endemic. This mountain range covers nearly 750,000 km^2.

II. Indo – Burma Region

The Indo-Burma Region is stretched over a distance of 2,373,000 km^2. In the last 12 years, 6 large mammal species have been discovered in this region: the Large-antlered Muntjac, the Annamite Muntjac, the Grey-shanked Douc, the Annamite Striped Rabbit, the Leaf Deer, and the Saola.

This hotspot is also known for the endemic freshwater turtle species, most of which are threatened with extinction, due to over-harvesting and extensive habitat loss. There are also 1,300 different bird species, including the threatened White-eared Night-heron, the Grey-crowned Crocias, and the Orange-necked Partridge.

III. The Western Ghats

The Western Ghats are present along the western edge of peninsular India and covers most of the deciduous forests and rain forests. As per UNESCO, it is home to at least 325 globally threatened flora, fauna, bird, amphibian, reptile and fish species. Originally, the vegetation in this region was spread over 190,000 km^2 but has been now reduced to 43,000 km^2. The region is also known for the globally threatened flora and fauna represented by 229 plant species, 31 mammal species, 15 bird species, 43 amphibian species, 5 reptile species and 1 fish species. UNESCO mentions that "Of the total 325 globally threatened species in the Western Ghats, 129 are classified as Vulnerable, 145 as Endangered and 51 as Critically Endangered."

Knowing in detail about the Western Ghats will be helpful for the aspirants for the Geography preparation.

IV. Sundaland

The Sundaland hotspot lies in South-East Asia and covers Singapore, Thailand, Indonesia, Brunei, and Malaysia. In the year 2013, the Sundaland was declared as a World Biosphere Reserve by the United Nations. This region is famous for its rich terrestrial and marine ecosystem. Sundaland is one of the biologically richest hotspots in the world which comprises 25,000 species of vascular plants, of which 15,000 are found only in this region.

Measuring biodiversity; interrelationship between diversity measures

Measures of Biodiversity

Several metrics can be used to measure biodiversity, such as:

- the number of species or **species richness**;

- the extent of uniform/even distribution among species referred to as s**pecies evenness;**
- the variation in the genetic make-up of organisms within a population or community referred to as **genetic diversity**;
- the characteristics or phenotypic differences within the community referred to as **phenotypic variance**;
- **the population number** is a measurement of the number of specific species within genetically distinct populations.

Species Richness

- The degree of diversity found within a specific ecological system is known as biodiversity.
- The total number of species found on Earth is frequently used to quantify the biodiversity of the planet.
- Thus, the species richness of an ecosystem is taken into account as one of the most popular methods for estimating biodiversity.
- Species richness is the measurement of all the species that are present in a given area.
- The ecosystem will be more stable if there are more species since more species mean more species richness.
- Increased species diversity will eventually boost biodiversity, which is a crucial component of preserving biodiversity.

Alpha Diversity

- Alpha diversity is a metric for species diversity within a given ecosystem or geographic region.
- The number of species found in the area of concern is how alpha diversity is expressed.
- As a result, species richness in that particular ecosystem is provided by alpha diversity.
- Compared to beta and gamma diversity, alpha diversity is a small-scale indicator.

Beta Diversity

- When species diversity varies between groups or ecosystems, it is referred to as beta diversity.
- Therefore, beta diversity enables the comparison of ecosystem biodiversity.
- The number of species that are particular to each system is measured in beta diversity.

Gamma Diversity

- Gamma diversity is a measurement for assessing a large area's total biodiversity.
- As a result, it calculates the total diversity of all the ecosystems in that area.
- The average species diversity in an ecosystem and the variation in species diversity between those habitats are the two factors that determine total diversity.
- Geographic-scale species diversity is one sort of gamma diversity.

Species Evenness

- Species evenness is a measurement of the relative abundance of various species in a given area.
- Greater species evenness can be seen in areas where all species are present in roughly equal numbers.
- For example, Areas 1 and 2 both include four different species of trees.
- However, one species actually dominates Area 2, and one of those species is quite rare (only one individual)
- Despite the exact same species richness in both areas, Area 1 has a better species evenness than Area 2, which results in a higher overall species diversity.

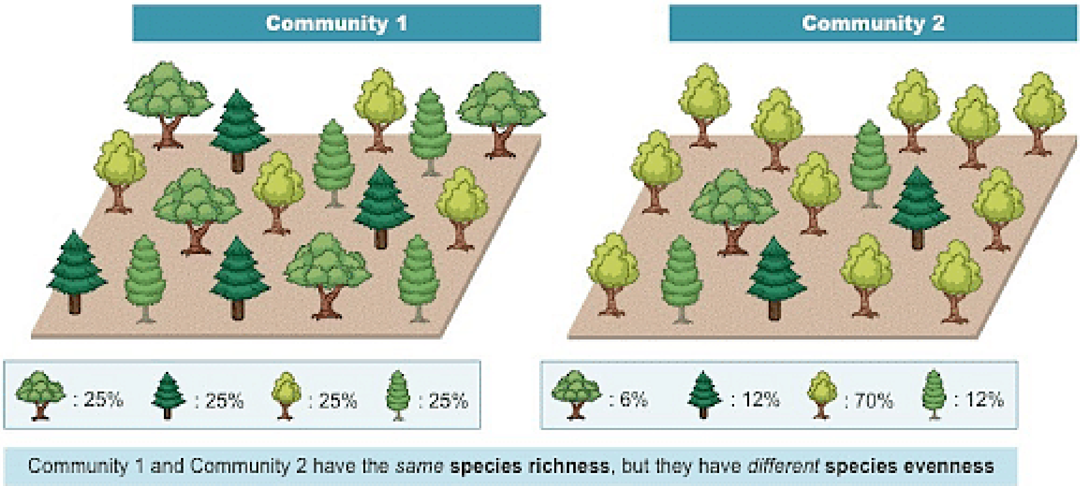


Fig: An illustration of Species Evenness

Biodiversity Measured as Genetic Diversity

- The total number of genes within a single species is referred to as genetic diversity.
- We know that species are made up of many different individuals, and that each individual is made up of thousands of different genes.
- Combining all of the genes in a species yields a measure of the species' genetic diversity.

Biodiversity Measured as Diversity of a Region's Endemic Species

- Endemic species are those that can only be found in one place and do not exist anywhere else on the planet.
- Endemic species have relatively small ranges and are much more vulnerable to human activity than more widely distributed species, because it is much easier to destroy all of the habitat in a small geographic range than it is in a large one.
- As a result, the presence of endemic species in a region provides additional information about the area's ecological quality or value.
- Endangered species include Hawaiian honeycreepers (only found in Hawaii), Javan rhinoceroses (only found on the Indonesian island of Java), and marine iguanas (which are found only in the Galapagos Islands).

Biodiversity Measured as Ecosystem Diversity

- One or more ecosystems may dominate a region, whether it is a landscape, a country, or a large swath of a continent.
- The more diverse the ecosystem types, the more species that could potentially live there.
- As a result, ecosystem diversity (the number of ecosystems in a region) can be used to estimate biodiversity.

Why is biodiversity measured?

Biodiversity is a measure that combines richness and evenness across species. It is often measured because high biodiversity is perceived a synonymous with ecosystem health. In general diverse communities are believed to have increased stability, increased productivity, and resistance to invasion and other disturbances.

Diverse habitats with a variety of plants can have benefits such as:

- Providing forage for a variety of insect and vertebrate species.
- Stability resulting from plants in the community that are able to survive drought, insect plagues, and/or disease outbreaks so that the site will have some soil protection/forage/etc. in those years.
- Plants containing a variety of genetic material that may be useful in long-term survival and stability of the community.
- The community benefits from a mixture of plants:
  • soils improve with nitrogen fixers, deep rooted plants bring nutrients up from soil layers below other plants roots.
  • some species work together so that both can survive (called commensalism) and therefore, diverse communities can be more stable.

- Healthy diverse plant communities generally have all niches filled and are theoretically less likely to be invaded by noxious or opportunistic introduced species.

Though seldom acknowledged, there are also disadvantages to high biodiversity:

- Diverse communities are often a sign of fragmented or somewhat degraded sites where much of species richness is contributed by disturbance species.
- Plant communities with high diversity can be more difficult to manage for grazing because different species of plants have different grazing tolerances and different rates of phenological development.
- Many plant communities are very stable with few species that are well adapted to the environment.

Biodiversity indices

• Species Richness indices

Species richness S is the simplest measure of biodiversity and is just a count of the number of different species in a given area. This measure is strongly dependent on sampling size and effort. Two species richness indices try to account for this problem:

i. Margalef's diversity index

$$D_{Mg} = \frac{S-1}{\ln N}, \qquad (1)$$

where N = population = the total number of individuals in the sample and S = the number of species recorded.

ii. Menhinick's diversity index

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

Despite the attempt to correct for sample size, both measures remain strongly influenced by sampling effort. Nonetheless they are intuitively meaningful indices and can play a useful role in investigations of biological diversity.

• Richness-Evenness indices

The first two indices are based on information theory. These indices are based on the rationale that the diversity in a natural system can be measured in a similar way to the information contained in a code or message.

iii. Shannon-Wiener diversity index

The most widely used diversity index in the ecological literature is the Shannon-Wiener diversity index

It assumes that individuals are randomly sampled from a very large community, and that all species are represented in the sample. The Shannon index is given by the expression

$$H' = -\sum_{i=1}^{S} p_i \ln p_i, \qquad (3) \text{ ,}$$

Where pi is the probability to find ni=Npi individuals in the *i*-th species (∑Si=1pi=1). ni of species i is called the **abundance** of this species.

iv. Brillouin index

Where the randomness cannot be guaranteed, for example when certain species are preferentially sampled, the Brillouin indexis a more appropriate form of the information index. It is calculated as follows:

$$H = \frac{1}{N}\left[\ln(N!) - \sum_{i=1}^{S} \ln(n_i!)\right], \qquad (4)$$

in which ni!=1×2×3×...×ni and ni = the number of individuals in species i and N=∑Si=1ni is the total number of individuals in the community.

v. Simpson 's index

One of the best known and earliest evenness measures is the Simpson 's index which is given by:

$$\gamma = \sum_{i=1}^{S} p_i^2. \qquad (5)$$

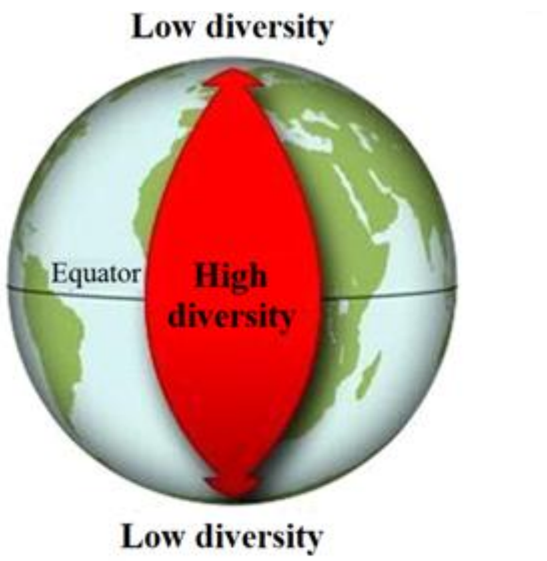
This index is used for large sampled communities. Simpson's index expresses the probability that any two individuals drawn at random from an infinitely large community belong to the same species. If all species are equally represented in the sample, then p_i=1/S or γ=1/S

Pattern of local and regional biodiversity

Biodiversity pattern in species is the understanding that the number of species found on Earth varies globally, locally as well as with time. Many variations can be present within species, biomes, ecosystems and a particular area. These variations of life forms across different areas and ecosystems are referred to as Biodiversity patterns. These patterns are crucial to studying the environment and even protecting it by preserving various life forms. The health of the environment is largely dependent on the Biodiversity patterns that exist within it.

The two important concepts that help us understand the pattern of biodiversity in Science are:

- **Latitudinal Gradient:** changes in the latitudinal position that affects biodiversity are called latitudinal gradients. These are essentially biogeographical patterns that determine how varying aspects of biodiversity change with their latitudinal geographical position.



- **Species Area Relationships:** this is depicted as a curve called the species-area curve. This curve explains the relationship between a particular geographical area, ecosystem or habitats and the number of species that can be found in the area. Typically, the measure of the area is directly proportional to the number of species found therein. Mathematically, it can be explained by the equation

log S = log C + Z log A

where,

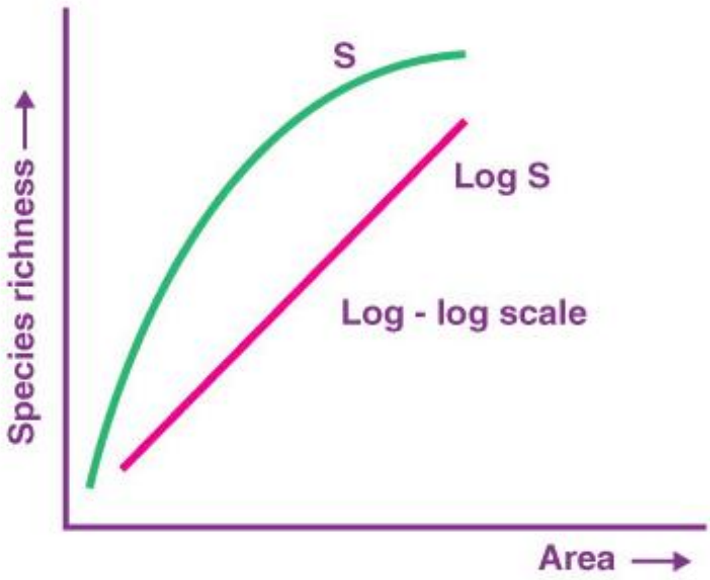
S = richness of species

C = Y-intercept

Z = regression coefficient

A = Area

The equation can be represented by the following diagram:



Probable questions:

1. What do you mean by biodiversity? Describe the different levels of biodiversity.
2. What is Species Diversity?
3. What do you mean by species richness and species evenness?
4. What are the components of species diversity?
5. State the importance of species diversity.
6. Mention two examples of the ecosystem with high species diversity
7. What do you mean by In-situ Conservation? Give example.
8. What do you mean by Ex-situ Conservation? Give example.
9. What are the characteristics of Tundra biome?
10. What are the characteristics of Desert biome?
11. What are the characteristics of grassland biome?
12. What are the characteristics of temperate deciduous forest biome.
13. What are the characteristics of Tropical rain forest biome?
14. What do you mean by Biological Hotspots? State its two characteristics.
15. Write down the importance of Western Ghats as Biological Hotspots in India.
16. Write down the importance of Eastern Himalayas as Biological Hotspots in India.

17. Elaborate different parameters for measuring biodiversity.
18. Why is biodiversity measured?
19. What do you mean by alpha diversity, beta diversity and gamma diversity?
20. State Shannon-Wiener diversity index. When this diversity index is applied?
21. What is Shanon's Index? How it is calculated?
22. Describe different pattern of local and regional biodiversity
23. Elaborate the idea of species area relationships with graphical representation.

Suggested Readings:

1. Biodiversity - Use and Conservation R.P. Singh and J.P. Singh
2. Textbook of Biodiversity by K.V. Krishna
3. Biodiversity – an Introduction by Kevin. J. Gaston and John. I. Spice

UNIT XII

Threats to species diversity; natural and human induced threats and vulnerability of species extinction; Red data book; rarity, endemism

Objective:

In this we will discuss about threats to species diversity; natural and human induced threats and vulnerability of species extinction; Red data book; rarity, endemism.

Introduction:

Some of the main threats to biodiversity are:

1. Human Activities and Loss of Habitat,

2. Deforestation,

3. Desertification,

4. Marine Environment,

5. Increasing Wildlife Trade

6. Climate Change.

7. Invasive Species. 8. Pollution.

9. PopulationGrowth and Over-consumption:

1. Human Activities and Loss of Habitat:

Human activities are causing a loss of biological diversity among animals and plants globally estimated at 50 to 100 times the average rate of species loss in the absence of human activities. Two most popular species in rich biomes are tropical forests and coral reefs.

Tropical forests are under threat largely from conversion to other land-uses, while coral reefs are experiencing increasing levels of over exploitation and pollution. If current rate of loss of tropical forests continues for the next 30 years (about 1 percent per year), the projected number of species that the remaining forests could support would be reduced by 5 to 10 percent relative to the forest in the absence of human disturbance.The rate of decline would represent 1000 to 10,000 times the expected rate of extinction without deforestation by humans. Some studies suggest that, globally, as many as one half of all mammal and bird species may become extinct within 200 to 300 years.

Biodiversity loss can result from a number of activities, including:

(a) Habitat conversion and destruction;

(b) Over-exploitation of species;

(c) Disconnected patches of original vegetation; and

(d) Air and water pollution.

Over the coming decades, human-induced climate change increasingly becomes another major factor in reducing biological/biodiversity. These pressures on biodiversity are, to a large extent, driven by economic development and related demands including the increasing demand for biological resources.

Activities that reduce biodiversity, jeopardize economic development and human health through losses of useful materials, genetic stocks, and the services of intact ecosystems. Material losses include food, wood, and medicines, as well as resources important for recreation and tourism. Losing genetic diversity, like losing species diversity, makes it even more likely that further environmental disturbance will result in serious reductions in goods and services that ecosystems can provide.

Decreased biodiversity also interferes with essential ecological services such as pollination, maintenance of soil fertility, flood controls, water purification, assimilation of wastes and the cycling of carbon and other nutrients.

2. Deforestation:

Forest ecosystems contain as much as 80 percent of the world's terrestrial biodiversity and provide wood fiber and biomass energy as well as critical components of the global cycles of water, energy and nutrient. Forest ecosystems are being cleared and degraded in many parts of the world.

Current projections suggest that demand for wood will roughly double over the next 50 years, which will make increasing use of sustainable forest practices more difficult. In addition to threats to biodiversity and potential shortages in the supply of forest products, the degradation of forests represents an enormous potential source of green house gas emissions. Forest ecosystems contain about three times the amount of carbon currently present in the atmosphere and about one-third of this carbon is stored above ground in trees and other vegetation and two-third is stored in the soil. When forests are cleared or burned, much of this carbon is released into the atmosphere. According to current estimates, tropical deforestation and burning account for about one quarter of carbon emissions into the atmosphere from human activities.

3. Desertification:

Desertification and deforestation are the main causes of biodiversity loss. Both processes are decisively influenced by the extension of agriculture. The direct cost of deforestation is reflected in the loss of valuable plants and animal species. Desertification process is the result of poor land management which can be aggravated by climatic variations. Converting wild lands to agriculture often involves ploughing the soils which leads in temperate regions to an average decline in soil organic matter between 25 and 40 per cent over twenty five years. Decreasing soil organic matter is always a clear indication of soil degradation, and often is accompanied by reductions in water infiltration, fertility, and ability to retain fertilizers. Ploughing also exposes soils to wind and water erosion, resulting in large-scale pollution of freshwater resources.

4. Marine Environment:

Oceans play a vital role in the global environment. Covering 70 per cent of the earth's surface, they influence global climate, food production and economic activities. Despite these roles, coastal and marine environment are being rapidly degraded in many parts of the globe. In coastal areas, where human activities are concentrated, pollution, over-exploitation of resources, development of critical habitats such as wetlands, and mangroves, and water-flow from poor land-use practices have led to drastic reductions in near shore fisheries production and aquatic biodiversity.

5. Increasing Wildlife Trade:

According to Nick Barnes, "Trade is another cause of biodiversity depletion that gives rise to conflict between North and South." Global trade in wildlife is estimated to be over US $ 20 billion annually. Global trade includes at least 40,000 primates, ivory from at least 90,000 African elephants, 1 million orchids, 4 million live birds, 10 million reptile skins, 15 million furs and over 350 million tropical fish.

6. Climate Change:

As climate warms, species will migrate towards higher latitudes and altitudes in both hemisphere. The increase in the amount of CO_2 in the air affects the physiological functioning of plant and species composition. Moreover, aquatic ecosystems, particularly coral reefs, mangrove swamps, and coastal wetlands, are vulnerable to changes in climate.

In principle, coral reefs, the most biologically diverse marine systems, are potentially vulnerable to changes in both sea level and ocean temperature. While most coral systems should be able to grow at a sufficient pace to survive a 15 to 95 cm sea-level rise over the next century, a sustained increase of several degrees centigrade would threaten the long-term viability of many of these systems.

7. **Invasive Species:**

Invasive species are 'alien' or 'exotic' species which are introduced accidentally or intentionally by human. These species become established in their new environment and spread unchecked, threatening the local biodiversity. These invasive alien species have been identified as the second greatest threat to biodiversity after habitat loss.

8. **Pollution:**

Pollution is a major threat to biodiversity, and one of the most difficult problems to overcome; Pollutants do not recognize international boundaries. For example, agricultural run-off, which contains a variety of fertilizers and pesticides, may seep into ground water and rivers before ending up in the ocean. Atmospheric pollutants drift with prevailing air currents and are deposited far from their original source.

9. **Population Growth and Over-consumption:**

From a population of one billion at the beginning of the 19th century, our species now numbers more than six billion people. Such rapid population growth has meant a rapid growth in the exploitation of natural resources— water, foods and minerals. Although there is evidence that our population growth rate is beginning to slow down, it is clear that the exploitation of natural resources is currently not sustainable. Added to this is the fact that 25 per cent of the population consumes about 75 per cent of the world's natural resources. This problem of over-consumption is one part of the broader issue of unsustainable use.

Reasons for species extinction

Main reasons for extinction are either natural or manmade. Through evolution, new species arise through the process of speciation and species become extinct when they are no longer able to survive in changing conditions or against superior competition. A typical species becomes extinct within 10 million years (1 crore year) of its first appearance although some species, called living fossils, survive virtually unchanged for hundreds of millions of years. Extinction, though, is usually a natural phenomenon; it is estimated that 99.9% of all species that have ever lived are now extinct.

Various anthropogenic activities causing extinction are manmade reasons. Only recently scientists have become alarmed at the high rates of recent extinctions due to various anthropogenic activities. Some of these anthropogenic activities include intentional or accidental introduction of invasive alien species, over exploitation and unscientific collection of Non-Timber Forest Produce (NTFPs) including medicinal plant, climate change, unsustainable tourism, habitat destruction, encroachment etc.

Red Data Book - Background

- The IUCN launched and maintains the Red Data Book, which was inspired by the world's conversation hawks.
- The IUCN is the world's most comprehensive inventory of biological species' global conservation status.
- The International Union for Conservation of Nature (IUCN) was established in 1948 with the goal of keeping a complete record of every species that has ever existed.
- Along with the centralized IUCN Book, many regional versions of the Red Data Book are maintained.
- Since 1965, the organization has worked to promote "nature conservation and sustainable use of natural resources."
- The Book was created in the **early 1960s by Soviet Union biologists** to research and record their findings of plants, animals, and fungi.
- It was originally known as the **Russian Federation's Red Data Book (RDBRF)**.
- The Red Data Book establishes concrete criteria for examining and evaluating the risks and threats to endangered species.
- When it comes to biological conservation, The Red Data Book is widely regarded as the most resource-rich and authoritative source, and it is widely used.

What is the Red Data Book?

- The Red Data Book includes the entire list of threatened species. The primary goal of this documentation is to provide comprehensive information for research and analysis of various species.
- It is a loose-leaf book containing data on the status of various species. The **International Union for Conservation of Nature (IUCN)** in Morges, Switzerland, publishes this volume, which is constantly updated.
- "Red" represents the danger that both plants and animals face today around the world.
- The IUCN's Special Survival Commission first issued the **Red Data Book in 1966** as a guide for the formulation, preservation, and management of listed species.
- The information in this book is more extensive for endangered mammals and birds than for other groups of animals and plants; coverage is also given to less prominent organisms facing extinction.

- This publication's **pink pages** feature **critically endangered species**. As the status of the species changes, new pages are sent to subscribers.
- **Green pages** are used for species that were once endangered but have now recovered to the point where they are no longer threatened. The number of pink pages grows over time. There are a pitiful few green pages.

Objectives of Red Data Book

- To support and promote biodiversity conservation while calling attention to corporations' unethical extinction drive.
- Influence domestic and international politics and use clout to sway policy decisions.
- To support and fund conversation methodologies and to promote sustainable living.
- To provide useful information to people who are interested in biological conservation.
- To record the flora and fauna of an evolving planet, as well as the flourishes and declines of endangered species.
- To emphasise the conservation measures used for critically endangered species, as well as the science involved in their preservation.

Advantages of Red Data Book

- It aids in the identification of all animals, birds, and other species, as well as their conservation status.
- It is used to assess the population of a particular species.
- The information in this book can be used to assess taxa on a global scale.
- We can estimate the risk of taxa going extinct globally with the help of this book.
- Provides a framework or guidelines for implementing protective measures for endangered species.

Disadvantages of Red Data Book

- The data in the Red Data Book is incomplete. This book is out of date on many species, both extinct and extant.
- The source of the data in the book has been speculated on and has been the subject of debate.

- This book contains an exhaustive list of all animals, plants, and other species, but no information on microbes.

The IUCN Red List :

The IUCN is perhaps best known for its Red List of Threatened Species (also known as the Red List). The Red List, established in 1964, provides the conservation status of plant and animal species around the world. IUCN members determine the risk of a species' extinction by utilizing criteria such as population size, subpopulations, the number of mature individuals, generation, the decline in population size, extreme fluctuations in population size, fragmented populations and habitats, habitat area size, and distribution of the population.

The Red List provides scientifically based information about species' survival, promotes public education about biodiversity, influences governmental policies, and offers advice about conservation efforts. The category assigned to each species is reassessed every 5 to 10 years by the IUCN Species Survival Commission Specialist Groups. This list is generally accepted as the most comprehensive information on the health and conservation of the world's species.

IUCN Classification

1. **Extinct (EX)**

- When there is no reasonable doubt that the last individual of a taxon has died, it is considered Extinct.
- Extensive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout a taxon's historic range fail to record an individual.

2. **Extinct in the Wild (EW)**

- A taxon is considered Extinct in the Wild when it is only known to survive in cultivation, captivity, or as a naturalised population (or populations) far outside its former range.
- Extensive surveys in known and/or expected habitat at appropriate times (diurnal, seasonal, annual) throughout a taxon's historic range fail to record an individual.

3. **Critically Endangered (CR)**

- A taxon is Critically Endangered when the best available evidence indicates that it meets any of the Critically Endangered criteria.
    - Population reduction by criteria (> 90% in the last ten years).

- Population size (a number less than 50 mature individuals).
- Quantitative analysis indicates a 50% chance of extinction in the wild in the next ten years.
- As a result, it is thought to be on the verge of extinction in the wild.

4. **Endangered (EN)**

- **An endangered species** is an organism that is on the verge of extinction
- A plant or animal species that is so rare that it is on the verge of extinction, particularly one that has been threatened by human activity.
- The destruction or pollution of a species' native habitat is a major factor in its endangerment or extinction.
- Other factors include overhunting, intentional extinction, and the unintentional or intentional introduction of alien species that compete for environmental resources with native species.

Criteria for endangered species

- Population size has decreased by ≥70% in the last ten years or three generations, whichever is longer.
- The estimated extent of occurrence is less than 5,000 km2, and the estimated area of occupancy is less than 500 km2.
- Population size is estimated to be less than 2,500 mature individuals, with a continuing decline of at least 20% expected within five years.
- The population size is estimated to be less than 250 mature individuals.
- Quantitative analysis indicates that the likelihood of extinction in the wild is at least 20% within 20 years or five generations.

5. **Vulnerable (VU)**

- A taxon is considered vulnerable when the best available evidence indicates that it meets any of the criteria for vulnerability, such as:
  - Population reduction (> 50% over the last 10 years).
  - The population is estimated to be less than 10,000 mature individuals.
  - The likelihood of extinction in the wild is at least 10% within the next 100 years.
  - As a result, it is thought to be on the verge of extinction in the wild.

6. **Near Threatened (NT)**

- A taxon is considered Near Threatened if it has been assessed against the criteria but does not currently qualify for Critically Endangered, Endangered, or

Vulnerable, but is close to qualifying for or is likely to qualify for a threatened category in the near future.

7. **Least Concern (LC)**

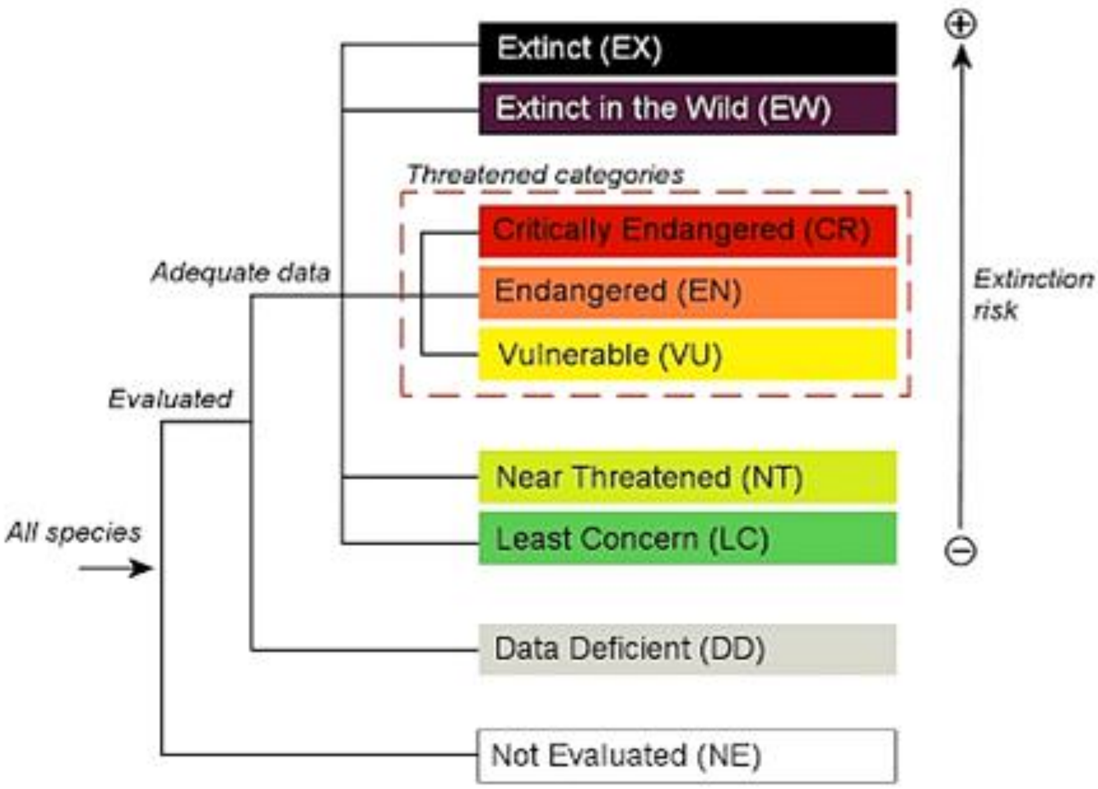
- When a taxon is considered Least Concern, it does not meet the criteria for Critically Endangered, Endangered, Vulnerable, or Near Threatened.
- This category includes taxa that are widespread and abundant.

8. **Data Deficient (DD)**

- When there is insufficient information to make a direct or indirect assessment of a taxon's risk of extinction based on its distribution and/or population status, the taxon is considered Data Deficient.
- Although a taxon in this category has been well studied and its biology is well understood, appropriate data on abundance and/or distribution are lacking.
- As a result, data deficiency is not a threat category. The inclusion of taxa in this category indicates that more information is needed and acknowledges the possibility that future research will reveal that the threatened classification is appropriate.

9. **Not Evaluated (NE)**

- When a taxon has not yet been evaluated against the criteria, it is classified as Not Evaluated.



Other categories :

a. Indeterminate: The taxon that is suspected of belonging to any of the threatened category but for which sufficient information is not available currently is called indeterminate taxon.

b. Lower risk : A taxon is in lower risk when it has been evaluated but does not qualify for any of the threatened category (critically endangered, endangered, vulnerable or near threatened) or data insufficient.

c. Rare: The taxon with small populations in the world that are not at present endangered or vulnerable are called rare taxon. These taxa are usually localized within restricted geographical areas or habitats or are thinly scattered over a more extensive range.

d. Out of danger : The taxon formerly included in any one of the extinction prone categories (critically endangered, endangered, vulnerable or near threatened) but which are now considered as relatively secured because of the effective conservation measures or the previous threat to their survival has been removed.

e. Endemic: Taxon with restricted geographical distribution are called endemic taxon. Due to such restricted distribution with small population size, they are vulnerable to both natural and anthropological threats of extinction.

Red Data Book of India

According to the IUCN Red Data Book of India, the following categories for endangered species have been identified.

- **Critically Endangered Mammals**

Malabar Civet (*Viverra civettina*)

- **Endangered Mammals**

Dhole / Asiatic wild dog or Indian wild dog (*Cuon alpinus*)

Lion-tailed macaque / wanderoo (*macaca silenus*)

Nilgiri langur / Nilgiri leaf monkey (*Trachypithecus john*)

Nilgiri tahr (*Nilgiritragus hylocrius*)

- **Vulnerable Mammals**

Gaur / Indian Bison (*Bos gaurus*)

Nilgiri marten (*Martes gwatkinsii*)

- **Critically Endangered Birds**

Spoon Billed Sandpiper (*Eurynorhynchus pygmeus*)

- **Near Threatened Reptiles**

Diaspora day gecko (*Cnemaspis sisparensis*)

Critically Endangered Species	Examples
Critically Endangered Mammals	Kondana Rat, Malabar Civet, Kashmir Stag, River Dolphin
Critically Endangered Anthropods	Rameshwaram Parachute Spider, Peacock Tarantula
Critically Endangered Fish	Pookode Lake Barb, Ganges River Shark, Pondicherry Shark
Critically Endangered Amphibians and Reptiles	Gharial, White spotted bush frog, Toad skinned frog

✓ Rare species

A **species** that is uncommon, few in number or not abundant. A species can be rare and not necessarily be endangered or threatened, for example, an organism found only on an island or one that is naturally low in numbers because of a restricted range. Such species are, however, usually vulnerable to any exploitation, interference, or disturbance of their habitats. Species may also be common in some areas but rare in others, such as at the edge of its natural range.

"Rare" is also a designation that the IUCN—The World Conservation Union gives to certain species "with small world populations that are not at present 'endangered' or 'vulnerable' but are at risk. These species are usually localized within restricted geographical areas or habitats or are thinly scattered over a more extensive range." Some American states have also employed this category in protective legislation.

The giant panda, kakapo, Amur leopard, **Himalayan brown bear, wild Asiatic buffalo, desert fox** etc are examples of rare species

✓ Endemism

Endemism is the condition of being *endemic*, or restricted in geographical distribution to an area or region. The area or region can vary in size, and is defined or identified in different ways. Endemism is an ecological classification in that it describes the range or distribution of a species, or group of species. For instance, entire families of different species of birds are endemic to the island of Madagascar. The term endemism can applied to many things, including diseases and natural phenomenon. Endemism in these cases refers to the "normal" or standard level of some measured observation within a specific geographic region or area.

Endemism is not to be confused with *indigenous*, a term which refers to the origins of a species. Indigenous refers to where a group originated. A species can be both endemic and indigenous to an area. However, some species thrive and exceed the bounds of their original indigenous location. This means that the species is no longer endemic, but is still indigenous to the original area. Once a species has reached a wide-spread, global distribution it is said to be *cosmopolitan*. Animals like whales, once indigenous to a specific mainland in the form of their 4-legged ancestors, are now cosmopolitan in distribution.

Endemic Species:

An endemic species is a species which is restricted geographically to a particular area. Endemism in a species can arise through a species going extinct in other regions. This is called *paleoendemism*. Alternatively, new species are always endemic to the region in which they first appear. This is called *neoendemism*. Both forms of endemism are discussed in more detail under the heading "Types of Endemism", below.

Endemic species, regardless of how they came to be restricted to a particular area, experience the same threats to their existence. The smaller the region more the threat toward the survival of the species. Any action that reduces the size of the land, or divides it in any way can significantly affect the normal patterns of the endemic species. While endemism and being *endangered* or *threatened* are different things, being endemic to a small area is often a warning sign that a species may become threatened or endangered.

This is not always the case, as many globally distributed species are also considered threatened or endangered. In recent years, many sharks have joined the list. While they are distributed throughout many of the ocean's waters, the harvesting of shark fins for soup has decimated their populations globally. Endemism sometimes protects species from being exploited globally, simply because of the fact that the species only exists in a small area. This can even make the species easier to protect, because the land can be placed under a *conservation easement* to restrict the construction and human impact on the land.

Probable questions:

1. Define biodiversity. Discuss the causes of loss of biodiversity.
2. Write a short note on Red Data Book of IUCN.
3. What is the Red Data Book? Describe the objectives of Red data book.
4. State the advantages and disadvantages of Red Data Book.
5. What is the main aim of IUCN Red List?
6. What are the 4 most critical categories of the IUCN Red List of Threatened Species?
7. What is vulnerable IUCN Red List?
8. Define nine IUCN categories.
9. Name one Critically Endangered Mammals of India according to Red Data Book.
10. Name Endangered Mammals of India according to Red Data Book.
11. Define Endemism and explain it.
12. Write short notes on Endemic species with examples.
13. Write short notes on Rare species with examples.

Suggested Readings:

1. Akçakaya, H.R. and Ferson, S. 2001. RAMAS® Red List: Threatened Species Classificationsunder Uncertainty. Version 2.0. Applied Biomathematics, New York.
2. Akçakaya, H.R., Ferson, S., Burgman, M.A., Keith, D.A., Mace, G.M. and Todd, C.A. 2000. Making consistent IUCN classifications under uncertainty. Conservation Biology 14: 1001-1013.
3. Baillie, J. and Groombridge, B. (eds). 1996. 1996 IUCN Red List of Threatened Animals. IUCN,Gland, Switzerland.
4. Burgman, M.A., Keith, D.A. and Walshe, T.V. 1999. Uncertainty in comparative risk analysis ofthreatened Australian plant species. Risk Analysis 19: 585-598.
5. Fitter, R. and Fitter, M. (eds). 1987. The Road to Extinction. IUCN, Gland, Switzerland.
6. Gärdenfors, U., Hilton-Taylor, C., Mace, G. and Rodríguez, J.P. 2001. The application of IUCN Red List Criteria at regional levels. Conservation Biology 15: 1206-1212.

UNIT XIII

Effective and minimum viable population, fragmentation of population; problems of genetic diversity; bottleneck; genetic drifts; inbreeding depression

Objective:

In this unit we will discuss about effective and minimum viable population, fragmentation of population; problems of genetic diversity; bottleneck; genetic drifts; inbreeding depression.

Minimum Viable Population Size

The idea that small populations are more vulnerable to extinction can be found in the work of MacArthur and Wilson's (1967) Theory of Island Biogeography. They proposed a model, which indicates that the probability of extinction varies with population size. An isolated island represents equilibrium between the number of immigrating species and number of species becoming extinct. Smaller islands have less number of species and, more important, smaller populations will have shorter time to extinction. This model implies that below a certain threshold population size of individuals for island species the expected time to extinction will be very short. And above that threshold the population will have relatively longer time of persistence. Shaffer (1981) defined MVP for any given species in any given habitat as the smallest isolated population having a 99% chance of remaining extant for 1000 years despite the foreseeable effects of demographic, environmental, genetic stochasticity, and natural catastrophes. Thus to avoid extinctions, the population must be sufficient to withstand such random events. Demographic stochasticity includes random factors that affect the birth rate and the death rate of population. If more animals die and few animals born, extinction can occur before the population can recruit themselves to a safe number again. Random variation in sex ratio and reproductive successes in females also lead population to decline and extinction. The effect of demographic stochasticity is greatest in small populations. Environmental stochasticity includes variations that are external to the population like rainfall, temperature, availability of food, and population of competitors, predators and diseases. Environmental stochasticity affects the population by influencing the demographic parameters. Natural catastrophes include fires, floods, earthquakes, and volcanic eruptions. Genetic stochasticity refers to the random processes involved in passing genes from one generation to the next. Genes may be lost from a small population and the gene frequencies may be changed due to drift or inbreeding.

Effective Population Size:

The concept of effective population size is fundamental to MVP size. The effective population size is the actual number of individuals that can breed to produce viable offspring. In other words the effective population size is the ideal population, which is able to maintain the same genetic diversity as the real population. Therefore, it is always necessary to find out the effective population number before the MVP size for that population can be estimated. The effective population size takes into several basic assumptions (Mace 1986):- a) random mating, b) no migration, c) no mutation, d) no selection, and e) non-overlapping generation. If any of these assumptions are violated in a population, the effective population size will differ from the census population size. In the real world, a population will almost never follow all the above assumptions at the same time and therefore the census population is usually greater than the effective population size. A census population consisting of the effective population size to avoid extinction over a given time is taken as the MVP for that population. Simberloff (1988) has pointed out two types of effective population size- the inbreeding effective population size, and the variance effective population size. The inbreeding effective population size is the size of an ideal population with the same rate of decrease in homozygosity as in the particular population, while the variance effective population size is the size of an ideal population with the same rate of variance due to drift as in the particular population. These two population sizes can be similar when population size is constant, and sometimes can be different. In a growing population the variance effective population will tend to be greater than inbreeding effective population size. In a declining population, the opposite occurs. In addition to random mating, no migration, no mutation, no selection and nonoverlapping generation, the effective population size will also vary because of different mating behaviours in monogamous and polygamous system.

Metapopulation:

In ecology, a regional group of connected populations of a species is called metapopulation. For a given species, each metapopulation is continually being modified by increases (births and immigrations) and decreases (deaths and emigrations) of individuals, as well as by the emergence and dissolution of local populations contained within it. As local populations of a given species fluctuate in size, they become vulnerable to extinction during periods when their numbers are low. Extinction of local populations is common in some species, and the regional persistence of such species is dependent on the existence of a metapopulation. Hence, elimination of much of the metapopulation structure of some species can increase the chance of regional extinction of species.

The structure of metapopulation varies among species. In some species one population may be particularly stable over time and act as the source of recruits into other, less stable populations. For example, populations of the checkerspot butterfly (*Euphydryas* *editha*) in California have a metapopulation structure consisting of a number of small satellite populations that surround a large source population on which they rely for new recruits. The satellite populations are too small and fluctuate too much to maintain themselves indefinitely. Elimination of the source population from this metapopulation would probably result in the eventual extinction of the smaller satellite populations.

In other species, metapopulation may have a shifting source. Any one local population may temporarily be the stable source population that provides recruits to the more unstable surrounding populations. As conditions change, the source population may become unstable, as when disease increases locally or the physical environment deteriorates. Meanwhile, conditions in another population that had previously been unstable might improve, allowingthis population to provide recruits.

Genetic diversity

Genetic diversity is the product of recombination of genetic material in the process of inheritance. It changes with time and space.

Sexual reproduction is important in maintaining genetic diversity as it gives unique offspring by combining genes of parents.

Mutation of genes, genetic drift and gene flow are also responsible for genetic diversity.

Figure 1: In this photo, notice the genetic diversity among maize species. Credit: [Luigi Guarino](), CC BY-SA [2.0]().

Importance of Genetic Diversity

- Genetic diversity gives rise to different physical attributes to the individual and capacity to adapt to stress, diseases and unfavourable environmental conditions.
- Environmental changes that are natural or due to human intervention, lead to the natural selection and survival of the fittest. Hence, due to genetic diversity, the varieties that are susceptible, die and the ones who can adapt to changes will survive.

- Genetic diversity is important for a healthy population by maintaining different varieties of genes that might be resistant to pests, diseases or other conditions.
- New varieties of plants can be grown by cross-breeding different genetic variants and produce plants with desirable traits like disease resistance, increased tolerance to stress.
- Genetic diversity reduces the recurrence of undesirable inherited traits.
- Genetic diversity ensures that at least there are some survivors of a species left.

Genetic Diversity Examples

- Different breeds of dogs. Dogs are selectively bred to get the desired traits.
- Different varieties of rose flower, wheat, etc.
- There are more than 50,000 varieties of rice and more than a thousand varieties of mangoes found in India.
- Different varieties of medicinal plant Rauvolfia vomitoria present in different Himalayan ranges differ in the amount of chemical reserpine produced by them.

Problems of genetic diversity?

If genetic diversity gets too low, species can go extinct and be lost forever. This is due to the combined effects of inbreeding depression and failure to adapt to change. In such cases, the introduction of new alleles can save a population.

Factors of Genetic Diversity

Genetic diversity is influenced by four events controlling evolution**: mutation, genetic drift, gene flow, and natural selection**. However, only mutations can produce completely new alleles.

1. Mutations

Mutations are changes in the nucleotide sequence on DNA. The occurrence of mutations is mainly due to the replacement or change in genes and chromosomes. Mutations can produce new alleles resulting in the change of a population's genetic structure. Spontaneous mutations are rare. They do not have a great effect in changing the genetic structure of a population, and they have a negligible effect in short periods. That's why mutations do not control evolution. However, mutations, along with other adaptation mechanisms that influence evolution, can be a remarkable source of genetic diversity in a population.

In multicellular organisms, mutations may occur either in a somatic cell or gametophytic cell (gametes). Mutations in somatic cells may disturb mitosis and this could lead to the formation of tumors. These mutations, however, are not transmitted to the following generations. Conversely, mutations in gametes are hereditary mutations that can be transmitted to offspring. These mutations affect genetic diversity in the long term.

2. Genetic drift

Genetic drift is a random change in the frequency of a certain allele within a population from one generation to another due to chance sampling events, which is less pronounced in large populations. Genetic drift occurs due to the random selection of some alleles to be inherited by offspring. It affects genetic diversity by fixing certain alleles and losing others since the change in alleles frequencies can produce more significant differences among different populations. Genetic drift affects small populations more than large ones because the probability of appearance of the effect of fixed or lost alleles is higher in comparison to small populations. It is not selective to useful genes; on the contrary, harmful or lethal genes may be fixed while useful genes may be lost.

Genetic drift contributes to the genetic diversity among populations since new recessive alleles may be fixed. It affects populations that have been exposed to events leading to a rapid reduction in population size, such as natural disasters that decrease the genetic diversity among populations.

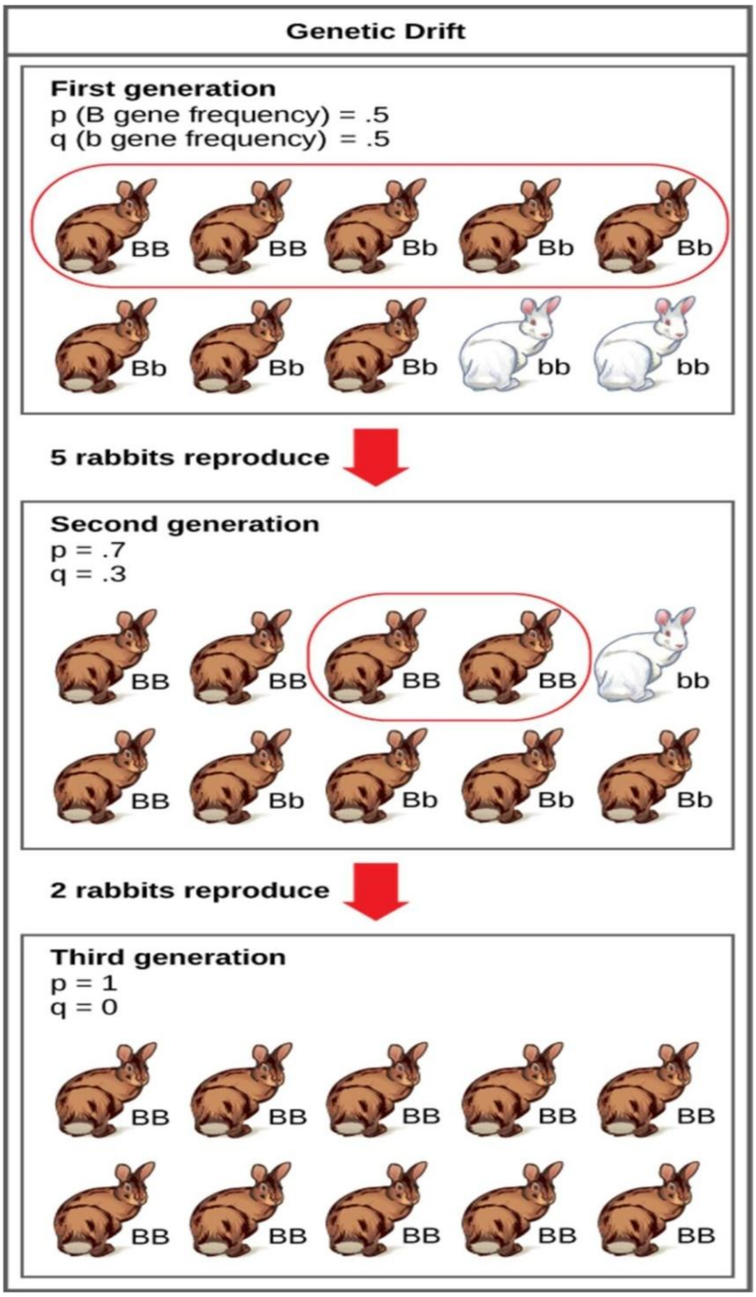
- **Genetic drift example**

Let's make the idea of drift more concrete by looking at an example. As shown in the diagram below, we have a very small rabbit population that's made up of 888 brown individuals (genotype *BB* or *Bb*) and 222 white individuals (genotype *bb*). Initially, the frequencies of the *B* and *b* alleles are equal.

What if, purely by chance, only the 555 circled individuals in the rabbit population reproduce? (Maybe the other rabbits died for reasons unrelated to their coat color, e.g., they happened to get caught in a hunter's snares.) In the surviving group, the frequency of the *B* allele is 0.70.70, point, 7, and the frequency of the *b* allele is 0.30.30, point, 3.

In our example, the allele frequencies of the five lucky rabbits are perfectly represented in the second generation, as shown at right. Because the 555-rabbit "sample" in the previous generation had different allele frequencies than the population as a whole, frequencies of *B* and *b* in the population have shifted to 0.70.70, point, 7 and 0.30.30, point, 3, respectively.

From this second generation, what if only two of the *BB* offspring survive and reproduce to yield the third generation? In this series of events, by the third generation, the *b* allele is completely lost from the population.



- **The bottleneck effect**

The bottleneck effect is an **extreme example of genetic drift** that happens when the size of a population is severely reduced. Events like natural disasters (earthquakes, floods, fires) can decimate a population, killing most individuals and leaving behind a small, random assortment of survivors.

The allele frequencies in this group may be very different from those of the population prior to the event, and some alleles may be missing entirely. The smaller population will also be more susceptible to the effects of genetic drift for generations (until its numbers return to normal), potentially causing even more alleles to be lost.

How can a bottleneck event reduce genetic diversity? Imagine a bottle filled with marbles, where the marbles represent the individuals in a population. If a bottleneck event occurs, a small, random assortment of individuals survives the event and passes through the bottleneck (and into the cup), while the vast majority of the population is killed off (remains in the bottle). The genetic composition of the random survivors is now the genetic composition of the entire population.

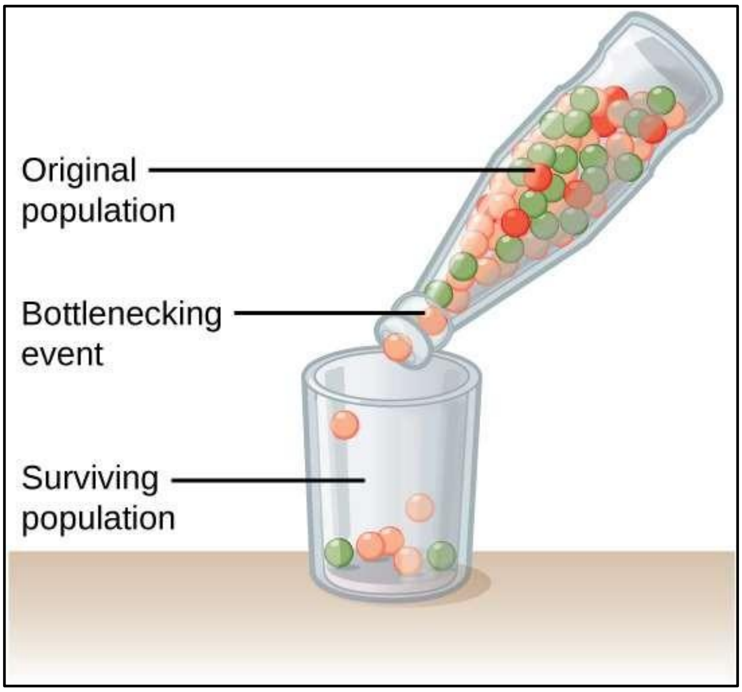


Figure 2: Bottleneck effect example: a natural disaster affects a population. Only a few individuals survive after the disaster and this could greatly limit the gene pool. Credit: Openstax.

A population bottleneck yields a limited and random assortment of individuals. This small population will now be under the influence of genetic drift for several generations.

- **<u>The founder effect:</u>**

The founder effect is another extreme example of drift, one that occurs when a small group of individuals breaks off from a larger population to establish a colony. The new colony is isolated from the original population, and the founding individuals may not represent the full genetic diversity of the original population. That is, alleles in the founding population may be present at different frequencies than in the original population, and some alleles may be missing altogether. The founder effect is similar in concept to the bottleneck effect, but it occurs via a different mechanism (colonization rather than catastrophe).

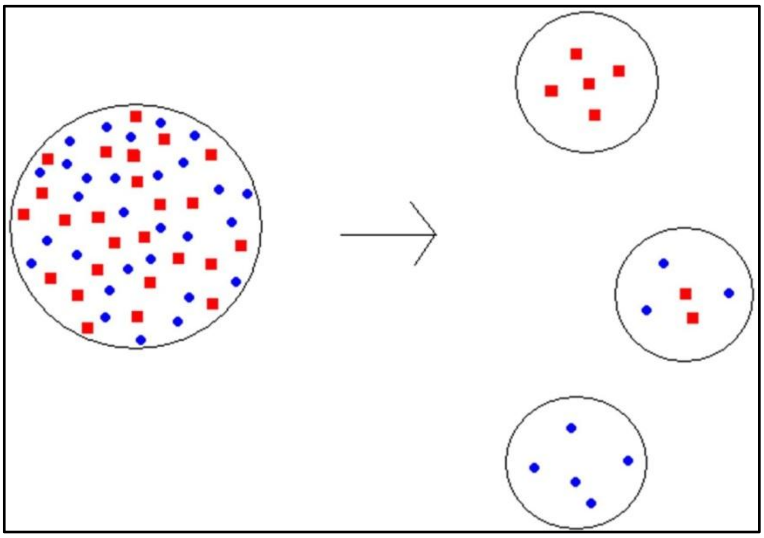


Fig 3: Simplified illustration of the founder effect

The original population consisting of equal amounts of square and circle individuals fractions off into several colonies. Each colony contains a small, random assortment of individuals that does not reflect the genetic diversity of the larger, original population. These small colonies will be susceptible to the effects of genetic drift for several generations.

In the figure above, you can see a population made up of equal numbers of squares and circles. (Let's assume an individual's shape is determined by its alleles for a particular gene).

Random groups that depart to establish new colonies are likely to contain different frequencies of squares and circles than the original population. So, the allele frequencies in the colonies (small circles) may be different relative to the original population. Also, the small size of the new colonies means they will experience strong genetic drift for generations.

3. Gene flow

Gene flow is also known as gene migration; it is defined as the transmission of alleles through populations. Gene flow means that new generations are produced carrying a certain allele that has been transmitted from a donor population to a recipient population. Both having different frequencies of this allele. For example, pollen may be spread to distant places by wind carrying alleles from a population with high allele frequency to another population with low allele frequency. However, the largest unit within which gene flow can readily occur is a species.

Gene flow is a very important mechanism that maintains genetic diversity among populations and contributes to the evolutionary process by migration of genes between two populations having different allele frequencies. This factor can produce new alleles or rearrangements of chromosomes when the new allele was not previously found in the recipient population. The effects of gene flow include increasing the genetic diversity and the introduction of new alleles among populations.

4. Natural selection

Natural selection is a process by which the gene pool of the population changes due to the reproduction of individuals that can resist environmental changes. It is an important method of population adaptation to environmental conditions during evolution. Individuals can resist environmental factors in the short term by physiological methods. However, long-term resistance requires changing the population's genetic composition to survive.

Natural selection is the transfer of useful alleles to the following generation leading to enhanced adaptability. Natural selection supports more adapted organisms while destroying less adapted individuals. Therefore, genetic material changes along with natural selection are the basis of evolution among species. The elimination of the less adapting alleles in the population eliminates the more susceptible organisms that cannot tolerate environmental changes. Consequently, natural selection influences the frequency of alleles in a population by affecting the contribution of individuals in next generations changing frequencies of genes.

Sexual selection results from either the direct competition for fertilization among males or sperms (same-sex members) or from the attraction of different sexes to each other. Sexual selection affects genetic diversity levels and accordingly it affects genetic evolution. Genetic diversity present among generations depends on the genes transmitted from both males and females across generations to keep genetic diversity.

Difference between Natural Selection and Genetic Drift:

Natural selection and genetic drift both result in a change in the frequency of alleles in a population, so both are mechanisms of evolution. However, the two processes differ in how they cause allele frequencies to change. Genetic drift causes evolution by random chance due to sampling error, whereas natural selection causes evolution on the basis of fitness.

In natural selection, individuals whose heritable traits make them more fit (better able to survive and reproduce) leave more offspring relative to other members of the population. That is, an individual with higher fitness is more likely to pass on its genetic material (alleles) to the next generation. The alleles that helped make this individual more fit will likely benefit the offspring in a similar way and should increase in frequency in the population over time. Thus, evolution by natural selection is not dependent on chance; it depends on an allele's effect on reproductive success. Alleles that improve fitness are likely to increase in frequency, while alleles that reduce fitness will decrease in frequency.

Genetic drift does not take into account an allele's effect on fitness because it is a random process. Think back to the rabbit population discussed above. What if the white rabbits were more fit than the brown rabbits (better able, on average, to survive and reproduce in the environment in which they lived)? In the example, the only two white rabbits in the population failed to reproduce, resulting in a loss of the beneficial alleles they carried. This result was purely due to chance and illustrates how genetic drift can result in the loss of beneficial alleles from a small population.

- **Adaptive Evolution**:

Natural selection only acts on the population's heritable traits: selecting for beneficial alleles and thus increasing their frequency in the population, while selecting against deleterious alleles and thereby decreasing their frequency—a process known as adaptive evolution. Natural selection does not act on individual alleles, however, but on entire organisms. An individual may carry a very beneficial genotype with a resulting phenotype that, for example, increases the ability to reproduce (fecundity), but if that same individual also carries an allele that results in a fatal childhood disease, that fecundity phenotype will not be passed on to the next generation because the individual will not live to reach reproductive age. Natural selection acts at the level of the individual; it selects for individuals with greater contributions to the gene pool of the next generation, known as an organism's evolutionary (Darwinian) fitness.

Fitness is often quantifiable and is measured by scientists in the field. However, it is not the absolute fitness of an individual that counts, but rather how it compares to the other organisms in the population. This concept, called relative fitness, allows researchers to determine which individuals are contributing additional offspring to the next generation, and thus, how the population might evolve.

There are several ways selection can affect population variation: stabilizing selection, directional selection, diversifying selection, frequency-dependent selection, and sexual selection. As natural selection influences the allele frequencies in a population, individuals can either become more or less genetically similar and the phenotypes displayed can become more similar or more disparate.

Inbreeding:

The process of mating of individuals which are more closely related than the average of the population, to which they belong, is called inbreeding. For example, parthenogenesis in animals and apomixes and self-fertilization in plants are the most extreme types of inbreeding.

Inbreeding in self-fertilizing pea plants was a real advantage to Mendel in his studies which provided pure lines of pea plants for his hybridization experiments. The term 'pure line' was coined by W. Johannsen in 1903 for the true breeding, self-fertilized plants.

Methods of Inbreeding:

In plants ova fertilized by the pollen of either the same plants (in case of bisexual plants) or of the other plant of the same genotype (in case of unisexual as well as bisexual plants), is called self- fertilization. However, in bisexual plants numerous structural and functional adaptations have been recorded which help plants with bisexual or hermaphrodite flowers avoid self-fertilization.

Normally, inbreeding is affected by restrictions in population size or area which brings about the mating between relatives. Since close relatives have similar genes because of common heritage, inbreeding increases the frequency of homozygotes, but does not bring about a change in overall gene frequencies. Thus, a mating between two heterozygotes as regards two alleles, A and a will result in half of the population, homozygous for either gene A or a and half of the population heterozygous like the parent but the overall frequencies of A and a remain unchanged:

Aa × Aa 1AA : 1Aa

Thus, inbreeding brings about the recessive gene to appear in a homozygous stale (aa). Once a recessive allele is in a homozygous state, natural selection can operate upon the rare recessives. Artificial selection is also possible as the homozygous recessives are phenotypically differentiated from the dominant population.

Genetic Effects of Inbreeding:

The continuous inbreeding results, genetically, in homozygosity. It produces homozygous stocks of dominant or recessive genes and eliminate heterozygosity from the inbred population.

For example, if we start with a population containing 100 heterozygous individuals (Aa) as shown in figure, the expected number of homozygous genotype increasing by 50% due to selfing or inbreeding in each generation. Thus, due to inbreeding in each generation the heterozygosity is reduced by 50% and after 10 generations we can expect the total elimination of heterozygosity from the inbred line and production of two homozygous or pure lines.

But, because a heterozygous individual possesses several heterozygous allelic pairs, we can conclude that inbreeding will operate on all genes loci to produce totally pure or homozygous offspring's. In human beings if inbreeding continued over a number of generations, it would results in increasing homozygosity, but somewhat slowly.

Inbreeding Depression:

In a heterozygote, the inbreeding increases the probability of homozygosity of deleterious recessive alleles in an inbred population. In other words, one of the consequence of inbreeding is a loss in vigour (i.e., less productive vegetatively and reproductively) which commonly accompanies an increase in homozygosity. This is called Inbreeding depression.

Inbreeding depression is found to occur due to following four features of inbreeding:

i. Increase in frequency of homozygotes,
ii. Increase in variability between different inbred families,
iii. Reduction in value of quantitative character in the direction of recessive values, and
iv. The dependence of this reduction in value upon dominance.

If this inbreeding effect is multiplied for many genes at many loci, there may be a large reduction in value for many traits, including those that affect fitness and survival. In com (maize) for example,

E.M. East (1908) and G. H. Shull (1909) studied the effects of inbreeding for 30 generations of inbreeding and found independently, that the yielding ability in these lines finally reduced to about one-third of the open-pollinated variety from which these samples were derived.

Both of these authors draw the following important conclusions:

i. A number of lethal and sub-vital types appear in early generations of selfing.
ii. The material rapidly separates into distinct lines, which become increasingly uniform fordifferences in various morphological and functional characteristics.
iii. Many of the lines decrease in vigour and fecundity until they cannot be maintained even under themost favourable culture conditions.
iv. The lines that survive show a general decline in size and vigour.

The practical applications of inbreeding:

1. Because inbreeding cause homozygosity of deleterious recessive genes which may result in defective phenotype, therefore, in human society, the religious ethics unknowingly and modem social norms consciously have condemned and banned the marriage of brothers and sisters. Further, the plant breeders and animal breeders too avoid inbreeding's in the individuals due to this reason.
2. The inbreeding because, results in the homozygosity of dominant allele, therefore, it is a best means of mating among hermaphrodites and self-pollinating plant species of several families. The animal breeders have employed the inbreeding to produce best races of horses, dogs, bulls, catties, etc.

The modern race horses, far example, are all descendants of three Arabian stallions imported into England between 1689 and 1730 and mated with several local mares of the slow, heavy type that had carried the medieval knights in heavy armour.

The fast runners of $F1$ were selected and inbred and stallions of the $F2$ appear as beginning points in the pedigrees of almost all modem race horses. This sort of inbreeding in also called line breeding which has been defined as the mating of animals in such a way that their descendants will be kept closely related to an unusually desirable individual.

Similarly, merino sheep are widely known as fine wool producers. They are the result of about 200 years of inbreeding. This strain was being developed in Spain in the 17th century by stock raisers.

They observed that the ancestors of the present day merino sheep had two coats of wool, one composed of long, coarse fibres arising from primary follicles, and a second coat composed of short fine wool arising from clusters of secondary follicles.

Intensive artificial selection was maintained for animals with more uniform production of fine wool and a lesser amount of coarse wool. For a time, Spain had a monopoly on the valuable merino sheep.

When France invaded Spain, merino sheep were moved to France where they were maintained and eventually distributed to other parts of the world. Merino sheep were taken to South Africa and in 1796 they were introduced into Australia which has since become the world's largest producer of fine wool.

Conclusion:

Unlike natural selection, genetic drift does not depend on an allele's beneficial or harmful effects. Instead, drift changes allele frequencies purely by chance, as random subsets of individuals (and the gametes of those individuals) are sampled to produce the next generation.

Every population experiences genetic drift, but small populations feel its effects more strongly. Genetic drift does not take into account an allele's adaptive value to a population, and it may result in loss of a beneficial allele or fixation (rise to 100\%100%100, percent frequency) of a harmful allele in a population.

The founder effect and the bottleneck effect are cases in which a small population is formed from a larger population. These "sampled" populations often do not represent the genetic diversity of the original population, and their small size means they may experience strong drift for generations.

Probable questions:

1. Define and explain Effective Population Size.
2. Define and explain Minimum Viable Population Size.
3. Define and explain metapopulation.
4. What is Genetic Drift? How it differs from Natural Selection?
5. Define and explain Founder Effect with examples.
6. Define and explain Bottle neck Effect with examples.
7. What is adaptive evolution?
8. What is inbreeding? Describe the mechanism.
9. Define gene flow.
10. Describe the role of natural selection.

Suggested Readings:

1. Akçakaya, H.R. and Ferson, S. 2001. RAMAS® Red List: Threatened Species Classifications under Uncertainty. Version 2.0. Applied Biomathematics, New York.
2. Akçakaya, H.R., Ferson, S., Burgman, M.A., Keith, D.A., Mace, G.M. and Todd, C.A. 2000. Making consistent IUCN classifications under uncertainty. Conservation Biology 14: 1001-1013.
3. Baillie, J. and Groombridge, B. (eds). 1996. 1996 IUCN Red List of Threatened Animals. IUCN,Gland, Switzerland.
4. Burgman, M.A., Keith, D.A. and Walshe, T.V. 1999. Uncertainty in comparative risk analysis ofthreatened Australian plant species. Risk Analysis 19: 585-598.

UNIT XIV

Biodiversity Resource Management: values and uses of biological diversity as source of foods, drugs and medicines

Objective:

In this unit we will discuss about biodiversity resource management, values and uses of biological diversity as source of foods, drugs and medicines.

Values of Biodiversity

Introduction

Biodiversity may be defined as the variety and richness in which life presents on the earth. It refers to the diversity in all species such as plants, animals and microorganisms. Since all species in an ecosystem are interrelated and dependent on one another, biodiversity has enormous value in the lives of all organisms, particularly for human beings. It would be difficult for life to continue and sustain without biodiversity.

Biodiversity serves a dual purpose in providing ecological functions. Biodiversity helps living beings procure food, fuel, fibre and other extractable commodities. Biodiversity is vital for the ecosystem because it provides regulatory, cultural, and sustaining functions.

Vegetation cover, for example, protects the land against erosion by binding soil particles and decreasing the impacts of water runoff. Similarly, crop cultivation is strongly dependent on the presence of pollinating insects.

Fundamental Value to Humans

Humans place a high value on biodiversity because they rely on it for social, economic, and environmental wellbeing. Biodiversity also helps to shape our culture and identity. Different character traits are regularly integrated into cultural practices.

Other elements of human wellbeing, such as wellness and economic and political security, depend on biodiversity. Encompassing prospective sources of multiple foods, medications, and energy can help economic activity and make the population healthier. When adjusted for use in wellbeing, agrarian, or industrial applications, biodiversity has proven to be extremely valuable.

Explain the Values of Biodiversity

Biodiversity is commonly defined in terms of species or groups of independent living organisms that can produce offspring. Marine mammals, fair-skinned deer, pine forests, fresh flowers, and micron-sized bacteria that cannot be seen with the naked eye are some of the examples of species that inhabit the earth.

Biodiversity has fundamental values, which can be categorised into:

1. Environmental values
2. Social values
3. Ecosystem services
4. Economic values
5. Value of consumptive use
6. Value of productive use
7. Moral and ethical values
8. Aesthetic values

1. Ecosystem values: The environmental values of biodiversity can be evaluated by analyzing the functions of the ecosystem. Ecosystem services, such as intensive agricultural production ecosystems, help in maintaining human needs and activities. These include the establishment and maintenance of fertile soil, retention of fresh groundwater resources through vegetation and the output of oxygen by ground plants and microalgae.

2. Economic Value: Biodiversity has a tremendous economic perspective on food, livestock feed, medicative, ethical, and social ideals. Biodiversity is an important resource for many industry sectors that regulate the world economy.

3. Consumptive use value: This refers to natural products that are used for food, such as livestock feed, wood products, fuelwood, and other purposes. Humans consume 40,000 flora and fauna species daily. Many people remain dependent on wildlife for the majority of their necessities, such as nutrition, temporary housing, and clothing.

4. Productive Use Value: This implies products that are sourced and commercially marketed. Almost all of the crops grown today have evolved from wild varieties. Biotechnologists are continuously experimenting with wild plant species to create new, more productive disease-resistant variants.

5. Ethical and Moral Value: Biodiversity has enormous economic potential in terms of food, livestock feed, medications, etc. Biodiversity is vital for many areas of the economy.

6. Aesthetic Value: The beauty of our planet is due to biodiversity. Otherwise, it would have looked like any other deserted planet, which is scattered throughout the universe. Biological diversity enhances the quality of life and contributes significantly to some of nature's most beautiful aspects. Biodiversity makes a significant contribution to the gorgeousness of the landscape.

Conclusion

Biodiversity may be defined as the variability with which life presents on the earth. It is difficult for life to sustain on this earth without biodiversity. The variety of organisms that exist on the earth is referred to as biological diversity. They are interconnected, as well as create an impact on each other. Biodiversity includes a wide range of plants, animals, and microorganisms. In layman's terms, biodiversity corresponds to the quantity and wide range of lifeforms found in a given geographic area. It refers to the various plant, animal, and microorganism species, as well as the genetic mutations they encompass and the ecosystems they form. Biodiversity helps to create and preserve cultural and religious values.

Uses of biological diversity

Some of the major importances of biodiversity are as follows:

1. Source of food and improved varieties
2. Drugs and Medicines
3. Fibres
4. Useful products
5. Ecosystem Services
6. Ecological Balance
7. Ecosystem stability, productivity and health.

Different species of living organisms have come into existence due to evolution, including human. So, human civilizations have developed on the foundation of biodiversity. The easily human societies were supported by various species of plants and animals.

1. Source of food and improved varieties:

There are nearly 80,000 species of edible plants. But only 30 species are mostly used as major source of food and 85% of the world's food production is met by cultivating less than 20 plant species. Three carbohydrate rich crops such as wheat, corn (maize) and rice alone yield nearly two-third of the food production.

To meet the growing demand of ever increasing human population, man is exploring new varieties of plants and animal food. For breeding improved varieties biodiversity is also used as a source material. To improve the desired traits, commercial/domesticated species are crossbred with their wild relatives. In this way, disease resistant and high yielding varieties of crops (e.g. wheat, rice, maize, sugar cane) and fruits have been developed.

Hybrid animal varieties have been produced to increase the production of milk, meat, eggs etc. This indicates the need for protecting biodiversity for breeding programmes in agriculture, horticulture, animal husbandry, sericulture, lac culture, poultry and fishery.

2. Drugs and Medicines:

Drugs and medicines are manufactured from various chemicals such as alkaloids, resins, fatty acids, glycosides, essential oils are obtained from medicinal plants. Ayurvedic medicines available in the market for treating numerous diseases in man are based on plant products. But unfortunately few species of these types of plants are investigated in detail for their medicinal value.

3. Fibres:

Fibre yielding plants such as cotton, flax, hemp, jute, etc. are the major sources of fibres. More and more varieties of plants are being explored for obtaining superior fibres.

4. Useful products:

Plants produce large number of useful products such as gums, dyes, rubber, tannins, latex, paper, tea, coffee, perfumes, waxes and dry fruits. Similarly, animal species provide wool, fur, skin, leather, honey, lac, silk, waxes, pearls, horn, antlers etc. for trade. Discovery of more such economically important species of plants and animals will yield more useful products for human use.

5. Ecosystem Services:

Biodiversity plays a major role in many ecosystem services such as replenishing oxygen through photosynthesis, pollination through bees, regulation of global climate, control of flood, and soil erosion, nutrient cycling", microbial waste treatment, biological control of pests etc.

6. Ecological Balance:

Biodiversity of species enhance ecological balance. Disappearance of any link in a food chain may upset nature's balance and create problems. For example, large scale killing of snakes will increase population of rats and hence large scale destruction of crops. Indiscriminate killings of tiger and lion will increase the population of herbivores that will damage forests, grass lands or crops, deforestation will affect rain full and thereby entire ecosystem and also human economy.

7. Ecosystem stability, productivity and health:

Biodiversity is essential for stability of an ecosystem. Communities having more species tend to be more stable than those with less species. A stable ecosystem is able to resist occasional disturbance. Ecosystem with higher biodiversity (example: tropical rain forest) are more productive than ecosystems with lower biodiversity (example: temperate forests). Biodiversity is essential for maintenance and health of ecosystems through the occurrence of various checks, controls, negative and positive feed backs.

Probable questions:

1. Define biodiversity.
2. Explain briefly the values of biodiversity.
3. Elaborate the different uses of biodiversity.
4. State the value of biodiversity to human.

Suggested Readings:

1. Biodiversity - Use and Conservation R.P. Singh and J.P. Singh

2. Textbook of Biodiversity by K.V. Krishna

3. Biodiversity – an Introduction by Kevin. J. Gaston and John. I. Spice

UNIT XV

Theories on relation between biodiversity and ecosystem function: Species Complementarity, Sampling effect and Redundancy

Objective:

In this unit we will discuss about theories on relation between biodiversity and ecosystem function: Species Complementarily, Sampling effect and Redundancy.

Introduction

Biodiversity-ecosystem function (BEF) theory was founded on the idea that levels of ecosystem functions (e.g., productivity, nutrient cycling, decomposition) and the stability of those functions depend directly on levels of biodiversity, including diversity of all biota at the level of genotypes, species, and functional groups (sets of physiologically or morphologically similar species). Ecosystem functions are typically estimated from measures of stocks, e.g., plant biomass or nutrient crop, in response to vascular plant diversity (which can be easily manipulated in experiments). To date, the vast majority of experimental tests indicate that, on average, diversity increases productivity.

The diversity of species and genes in ecological communities affects the functioning of these communities. These **ecological effects of biodiversity** in turn are affected by both climate change through enhanced greenhouse gases, aerosols and loss of land cover and biological diversity, causing a rapid loss of biodiversity and extinctions of species and local populations. The current rate of extinction is sometimes considered a mass extinction, with current species extinction rates on the order of 100 to 1000 times as high as in the past.

The two main areas where the effects of biodiversity on ecosystem function have been studied are the relationship between diversity and productivity, and the relationship between diversity and community stability. More biologically diverse communities appear to be more productive (in terms of biomass production) than are less diverse communities, and they appear to be more stable in the face of perturbations.

Also animals that inhabit an area may alter the surviving conditions by factors assimilated by climate.

Definitions

Biodiversity is not easily defined, but may be thought of as the number and/or evenness of genes, species, and ecosystems in a region. This definition includes genetic diversity or the diversity of genes within a species, species diversity, or the diversity of species within a habitat or region, and ecosystem diversity, or the diversity of habitats within a region.

Two things commonly measured in relation to changes in diversity are productivity and stability. Productivity is a measure of ecosystem function. It is generally measured by taking the total aboveground biomass of all plants in an area. Many assume that it can be used as a general indicator of ecosystem function and that total resource use and other indicators of ecosystem function are correlated with productivity.

Stability is much more difficult to define, but can be generally thought of in two ways. General stability of a population is a measure that assumes stability is higher if there is less of a chance of extinction. This kind of stability is generally measured by measuring the variability of aggregate community properties, like total biomass, over time. The other definition of stability is a measure of resilience and resistance, where an ecosystem that returns quickly to an equilibrium after a perturbation or resists invasion is thought of as more stable than one that does not.

Productivity and stability as indicators of ecosystem health

An unstable ecosystem will be more likely to lose species. Thus, if there is indeed a link between diversity and stability, it is likely that losses of diversity could feedback on themselves, causing even more losses of species. *Productivity*, on the other hand, has a less clear importance in community ecology. In managed areas like cropland, and in areas where animals are grown or caught, increasing productivity increases the economic success of the area and implies that the area has become more efficient, leading to possible long term resource sustainability. It is more difficult to find the importance of productivity in natural ecosystems.

Beyond the value biodiversity has in regulating and stabilizing ecosystem processes, there are direct economic consequences of losing diversity in certain ecosystems and in the world as a whole. Losing species means losing potential foods, medicines, industrial products, and tourism, all of which have a direct economic effect on peoples' lives.

Effects on community productivity

- **Complementarity** Plant species coexistence is thought to be the result of niche partitioning, or differences in resource requirements among species. By complementarity, a more diverse plant community should be able to use resources more completely, and thus be more productive. Also called niche differentiation, this mechanism is a central principle in the functional group approach, which breaks species diversity down into functional components.

- **Facilitation** Facilitation is a mechanism whereby certain species help or allow other species to grow by modifying the environment in a way that is favorable to a co-occurring species. Plants can interact through an intermediary like nitrogen, water, temperature, space, or interactions with weeds or herbivores among others. Some examples of facilitation include large desert perennials acting as nurse plants, aiding the establishment of young neighbors of other species by alleviating water and temperature stress and nutrient enrichment by nitrogen-fixers such as legumes.

- **The Sampling Effect** The sampling effect of diversity can be thought of as having a greater chance of including a species of greatest inherent productivity in a plot that is more diverse. This provides for a composition effect on productivity, rather than diversity being a direct cause. However, the sampling effect may in fact be a compilation of different effects. The sampling effect can be separated into the greater likelihood of selecting a species that is

1) Adapted well to particular site conditions, or

2) Of a greater inherent productivity. Additionally, one can add to the sampling effect a greater likelihood of including

3) A pair of species that highly complement each other, or

4) A certain species with a large facilitative effect on other members of the community

What is the relationship between biodiversity and ecosystem functioning?

Increasing species diversity can influence ecosystem functions — such as productivity — by increasing the likelihood that species will use complementary resources and can also increase the likelihood that a particularly productive or efficient species is present in the community.

Sampling effect: Its role in biological invasions

Sampling effect refers to the effect of introducing into a new environment a selected sub-sample of a species' many possible genotypes. "The interplay between native genetic diversity and a species' introduction history ultimately determines the genetic diversity introduced. For instance, while ornamental trees tend to be transported in lower numbers and introduced in low densities, forestry species tend to be transported in higher numbers and introduced in high densities. Trees introduced for erosion control are often transported in high numbers and introduced into particularly vulnerable habitats. Artificially selected traits for ornamentation [flower, fruit, and foliage traits] and forestry [rapid growth, disease resistance, environmental hardiness] are also often positively linked to invasion success. There are also substantial efforts to introduce and improve mycorrhizas for many forestry species, which may cause substantial increases in tree invasiveness following fungal introductions.”

What is the sampling effect of biodiversity?

The Sampling Effect The sampling effect of diversity can be thought of as having a greater chance of including a species of greatest inherent productivity in a plot that is more diverse. This provides for a composition effect on productivity, rather than diversity being a direct cause.

What is the redundancy hypothesis in biodiversity?

According to the redundancy hypothesis, species that play the same roles in the ecosystem (sometimes referred to as a guild) can compensate for each other if some are lost under particular conditions. In this way, species redundancy enhances the ability of an ecosystem to recover from a disturbance (resilience).

What is redundant ecosystem function?

Redundancy is a characteristic of ecological systems which arises when “different species perform the same functional role in ecosystems so that changes in species diversity do not affect ecosystem functioning”, and must be defined relative to the system being studied.

Probable questions:

1. Define biodiversity.
2. Describe Species Complementarity.
3. What is the role of productivity and stability as indicators of ecosystem health?
4. What is the role of sampling effect in biological invasions?
5. State the redundancy hypothesis in biodiversity.

Suggested Readings:

1. Biodiversity - Use and Conservation R.P. Singh and J.P. Singh

2. Textbook of Biodiversity by K.V. Krishna

3. Biodiversity – an Introduction by Kevin. J. Gaston and John. I. Spice

UNIT XVI

The economics of biodiversity and ecosystem function

Objective:

In this unit we will discuss about the economics of biodiversity and ecosystem function.

Introduction:

The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative focused on "making nature's values visible". Its principal objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels. The TEEB study was launched by Germany and the European Commission in response to a proposal by the G8+5 Environment Ministers in Potsdam, Germany in 2007. Its aim was to develop a global study on the economics of biodiversity loss.

The biosphere, which is the part of Earth that is occupied by living organisms, is a self organising, regenerative entity. Its rhythms, for example the seasons, shape the regeneration patterns of the living world. But living systems in turn make use of the non-living, or abiotic, constituents of the biosphere and transform them. Water, carbon and nitrogen cycles are expressions of that. Because the ability to regenerate is a characteristic of living systems, the biosphere's regeneration is key to the sustainability of the human enterprise. Regenerations of the living world at various scales and periodicity are synchronized via natural processes that are still not understood well.

Plants, algae and many bacteria capture energy from the sun, which is why they are called primary producers. The energy they capture, along with other abiotic materials, flows through ecosystems and enables a wide range of natural processes to function, including biomass production, nutrient cycling and water dynamics. These processes support biodiversity, but the influence is mutual, for biodiversity strengthens the processes, enabling nature to renew constantly.

The economics of biodiversity is thus the economics of the entire biosphere. In addition to produced capital and human capital, the economics of the biodiversity includes what we may call 'natural capital'. For example, a region that relies predominantly on only oil production is not economically diverse, while another that sports a vibrant manufacturing and personal services sector in addition to oil is said to be more economically diverse.

What is biodiversity?

Biodiversity is the sum of all life on earth. Every single individual lifeform from the smallest bacteria in the soil to the largest whale in the sea, is a component of Earth's biodiversity. But biodiversity doesn't stop at the individual. Biodiversity is also the relationships between these life forms and their habitat. That includes the relationship between plankton and whales that help produce oxygen in the atmosphere, seeds and rhinos that help plant forests, and bacteria and plants that change the chemistry of soils.

Biodiversity is an abbreviation of the term "biological diversity" which was coined in the mid-1980s with the help of the legendary tropical biologist, Thomas Lovejoy.

In the sciences, biodiversity is measured at several levels: genetic, species, communities, and ecosystems.

Humans are very much a member of the biodiversity community, and our own cultural diversity is increasingly recognized to be a product of local biodiversity. Culture is closely connected to the wild nature from which human communities emerge. The term "bio-cultural diversity" describes the relationship between human culture and the surrounding ecology.

Biodiversity tends to be far higher in the tropics than in cold, polar regions, meaning that in the tropics there are the most species, more genetic data, and more complex ecological interactions. Still, even the coldest, darkest regions, from the polar seas to the deepest caves, are rich in life forms. And **each and every one of these life forms contributes something important to the chemistry of their, and our, environment.** The highest quality biodiversity is often found in two types of places: protected area wild lands and those territories stewarded by Indigenous Peoples.

Biodiversity: why does it matter?

Earth's biodiversity is its most valuable and most necessary resource. Biodiversity is the primary source of Earth's biosphere – the life web that produces everything humans need most: food, water, many modern medicines, and air. While other planets are likely rich in minerals of high monetary value here on Earth, no other planet that we know of has the conditions necessary for human civilization.

Earth's biodiversity is the very basis for our own survival. This is demonstrated repeatedly, across the planet, at the macro and microscopic scale. Without plants, there would be no oxygen. Without bees, many of our crops would vanish. Other benefits of biodiversity are even more fundamental. The hardwood trees in the rainforests that are our most effective above-ground carbon sinks are also the product of the relationship between seeds and the fruit-eating animals that eat them. Trees are up to 500x more likely to germinate when the seeds have first passed through the digestion system of a bat, monkey, or elephant.

Microscopic biodiversity in our soils creates the chemical conditions necessary for healthy, abundant, and sustainable crops. Many new medicines are found in nature, including cancer fighting fungi and pain killing tree resins.

Economically, the services provided by biodiversity are estimated to be double the world's annual GDP – although this number is difficult to calculate as many of biodiversity's life-giving services cannot be replicated at scale by human technology.

Biodiversity in ecosystems

Traditionally, environmental and resource economists studied Nature's resources, such as fisheries, forests, lakes, air sheds, coastal waters, minerals and fossil fuels. For the economics of biodiversity, it proves useful to think of the biosphere instead in terms of constituents we call ecosystems. Ecosystems combine the abiotic environment with biological communities (plants, animals, fungi, microorganisms) to form self-organising, regenerative functional units, by which we mean combinations of life forms that control such fluxes as that of energy (e.g. photosynthesis), nutrients (e.g. nitrogen fixation) and organic matter (e.g. decomposition of organic waste).

Ecosystems are capital goods, like produced capital (roads, buildings, ports, machines). As in the case of produced capital, ecosystems depreciate if they are misused or are overused. But they differ from produced capital in three ways:

(i) depreciation is in many cases irreversible (or at best the systems take a long while to recover);

(ii) it is not possible to replicate a depleted or degraded ecosystem; and

(iii) Ecosystems can collapse abruptly, without much prior warning.

Ecosystems regenerate as part of Nature's rhythmic cycles. New forests emerge from the ashes of fires, rising from self-sown seeds and shoots from the roots of plants. We confirm below that biodiversity enables that regeneration to occur. It affects both living and non-living parts of ecosystems, which are connected through nutrient cycles and energy flows. Ecosystems also differ enormously depending on a range of factors, such as the underlying geology, climate, nutrient and chemical status of the soils, hydrology, prevailing winds and season. About 85% of plant species inhabit entirely within just over a third of Earth's land surface. Some ecosystems are highly diverse, such as tropical rainforests, while others have low diversity such as polar ecosystems. But the latter hold ice sheets, whereas the former do not. Protecting a million square miles of tropical rainforest has different consequences from protecting the same area of a polar landscape.

Biodiversity is key to the processes governing ecosystems. However, an ecosystem's productivity and resilience to disturbances depend less on the taxonomy of plants, animals and microorganisms than on them performing particular functions. The biodiversity in a wetland that filters water effectively differs from the biodiversity needed in woodland that supplies timber, which in turn differs from the biodiversity in grassland that supports wildlife. In each case, ecosystem productivity is determined by root structure, biomass above ground, leaf display, soil quality, crown architecture and wood production and composition.

Individual actors in ecosystems include organisms that pollinate, decompose, filter, transport, redistribute, scavenge, fix gases and so on. Nearly all organisms that help to produce those services are hidden from view (a gram of soil may contain as many as 10 billion bacterial cells).

Ecosystems as assets

The Review recognizes the biosphere as a web of interconnected self-regenerative entities called 'ecosystems'. Processes governing ecosystems are non-linear. Moreover, they differ among one another both in speed and spread, which is why even the decision to designate a patch of the environment as an ecosystem depends on the context - a hedgehog's gut is as much an ecosystem as the woodland in which the hedgehog resides.

Individual actors in ecosystems include organisms that, among other activities, pollinate, decompose, filter, transport, redistribute, scavenge, and fix gases. Nearly all organisms that help to produce those services are hidden from view (a gram of soil may contain as many as 10 billion bacterial cells), which is why they are almost always missing from popular discourses on the environment. But their activities enable ecosystems to maintain a genetic library, preserve and regenerate soil, fix nitrogen and carbon, recycle nutrients, control floods, mitigate droughts, filter pollutants, assimilate waste, pollinate crops, operate the hydrological cycle and maintain the gaseous composition of the atmosphere. These are what ecologists call 'regulating and maintenance services'. The processes that give rise to them are in large measure complementary to one another: degrading one severely can be expected to threaten the others. Biodiversity, by which is meant the diversity of life, is a characteristic of ecosystems. The Review builds on our increased understanding of the sense in which biodiversity contributes positively to ecosystem productivity. The economics of biodiversity is thus the economics of the entire biosphere. In addition to produced capital and human capital, the economics of the biodiversity includes what we may call 'natural capital'.

Regulating and maintenance services provide the basis on which we draw upon Nature's 'provisioning goods', such as food, timber, medicines, dyes, fibres, and fresh water, and enjoy 'cultural services', such as landscapes of tranquillity, beauty, even sacredness. The Review shows that there is a tension between humanity's needs for these two classes of goods and services. Private companies are in large measure unable to capture the returns from investment in regulating and maintenance services. That's because the services are in all too many cases 'non-excludable': companies cannot confine the benefits to those who pay for them. So, they invest mostly in those forms of natural capital that are direct inputs for provisioning services (farms, plantations, houses, manufactured goods, and transportation), whose products are excludable. That practice has eroded Nature's regulating and maintenance services. Non-market institutions have been introduced to protect cultural services (state parks and Nature reserves). Non-excludability is a reason the economics of biodiversity pays particular attention to 'externalities', which are the unaccounted consequences for others of our actions.

Because the biosphere is a tangled web of ecosystems, the Review, unlike the economics of global climate change, does not offer sharp formulae for policy, such as a social price for biomass. It does not prescribe 'biomass offsetting markets'. That's because a unit of biomass in a particular location in one ecosystem (e.g. a tropical rainforest) has widely different roles to play from a unit of biomass in another (e.g. in a grassland). Differences arise because the processes governing ecosystems are entangled with one another. Their entanglement is the reason ecosystems harbour what may be called 'natural externalities'. If biomass offsetting markets were introduced, brokers could profitably purchase units of biomass from ecologically productive places and offset them in ecologically unproductive places, making a profit. Further institutional mechanisms would then be needed to regulate such transactions. The Review speaks of ecosystems as the source of Nature's supply of goods and services; it does not build the economics of biodiversity on units of biomass.

The economics of ecosystem functions

Objectives In economic terms ecosystems must be regarded as a special form of capital assets. Like reproducible capital assets (roads, buildings, and machinery), ecosystems depreciate if they are misused or are overused. But ecosystems differ from reproducible capital assets in several ways. Depreciation of natural capital may be irreversible, or the systems take a long time to recover. Generally speaking, it isn't possible to replace a depleted or degraded ecosystem by a new one. And ecosystems may collapse abruptly, without much prior warning. Because ecosystems are threatened by human activities, it is important to better consider long term ecosystem health and its role in enabling human habitation and economic activity. To help inform decision-makers, many ecosystem services are being assigned economic values, often based on the cost of replacing such services with anthropogenic alternatives. The on-going challenge of prescribing economic value to nature is prompting shifts in how we recognize and manage the environment, social responsibility, business opportunities, and humanity's future.

Some cynics claim that the term 'ecosystem services', in addition to the term biodiversity, starts to become another environmental buzzword or complexity blinder. Nevertheless, during the last years, a considerable intellectual development in the understanding of ecosystem goods and services has taken place and interest has grown in refining the analysis and evaluation at various scales. Moreover, ecosystem services emerge in many national initiatives, such as the UK National Ecosystem Assessment – an advanced interdisciplinary assessment of ecosystems and their services.

The three interrelated goals of ecological economics are sustainable scale, fair distribution, and efficient allocation. All three of these contribute to human well-being and sustainability. Distribution has many different impacts, not the least of which is its impact on social capital and on quality of life.

Probable questions:

1. What is biodiversity?
2. Discuss the role of biodiversity in nature.
3. Describe shortly the economics of biodiversity.
4. Describe the biodiversity in ecosystems.
5. How the ecosystem is considered as assets in nature?
6. Elaborate the economics of ecosystem functions.
7. Mention the full form of TEEB. What is its function?

Suggested Readings:

1. Gerrard, P., (2004), "Integrating Wetland Ecosystem Values into Urban Planning: The Case of That Luang Marsh, Vientiane, Lao PDR", IUCN – The World Conservation Union Asia Regional Environmental Economics Programme and WWF Lao Country Office, Vientiane.
2. Emerton, L. (1994), "An Economic Valuation of the Costs and Benefits in the Lower Tana Catchment Resulting from Dam Construction", report prepared by Acropolis Kenya Ltd for Nippon Koei, Nairobi.
3. https://www.cbd.int/financial/values/unitedkingdom-valueliterature.pdf

Unit XVII

Landscape Ecology: a) Theories in landscape ecology. Hierarchy theory and the structure of the landscape, Percolation theory, The systems source sink b) Scale and landscape, Scaling the landscape, Change of scale perception. Importance of parameters at different scales

Objective:

As interested in identifying best practice as it is in progressing landscape theory, the Landscape Series particularly welcomes problem-solving approaches and contributions to landscape management and planning. The ultimate goal is to facilitate both the application of landscape research to practice, and the feed back from practice into research.

What is Landscape Ecology?

Landscape ecology emphasizes the interaction between spatial pattern (landscape structure) and ecological processes that is, the causes and consequences of spatial heterogeneity across a range of scales.

Landscape is heterogenous area composed of several ecosystems.

The term "landscape ecology" was introduced by the German biogeographer Carl Troll (1939).

Factors of landscape ecology

landscape ecology ... focuses on

(1) the spatial relationships among landscape elements, or ecosystems

(2) the flows of energy, mineral nutrients, and species among the elements.

(3) the ecological dynamics of the landscape mosaic through time. (Forman 1983)

Landscape metrics are important tools which are used to understand landscape structure and landscape changes.

To use metrics, numeric data is obtained related to landscape structure. Numeric data is produced

Natural Landscape:- landforms, such as mountains, hills, plains, and plateaus. Lakes, streams, soils (such as sand or clay), and natural vegetation are other features of natural landscapes.

Landscapes are dynamic systems. Human affects them continuously. Depending on intensive human effects, pressure was increased on Landscapes. Consequently, landscapes were changed over time. There are negative effects of pressures on landscape and species living in the area.

Landscape structure has two qualities. These are **composition** and **configuration**.

→ **Landscape composition:** It defines the quality of the landscape patches, scattered-in landscape. The composition is not a precise identification of the mosaic structure of the landscape. But it is a good indicator for living environment suitability of some species.

→ **Landscape configuration:** Configuration refers to the spatial characteristics. It refers to spatial characteristics same as the spatial distribution of land cover. Connectivity and fragmentation are known with understand Landscape function.

Theories in landscape ecology:

Complexity is one state of the universe but, for many reasons, this condition has been maintained ior a long time at the borders of scientific pragmatism.

As argued by Manson (2001), is possible to break complexity research into three main parts: "Algorithmic complexity", "Deterministic complexity" and "Aggregate complexity".

Algorithmic complexity takes into account mathematical complexity theory and information theory.

Different theories can be presented to explain how complexity arises, we have chosen three hypotheses with very broad implications:

1. **Uncertainty hypothesis (UH):**

   According to this hypothesis, complexity is a connected with the concept unpredictability of phenomena. Such uncertainty reduces the possibility for a system to couple with another system.

For instance: a snow patch on the mountains of the Mediterranean region has no chance to survive in the hot summers of the present-day climate, but the shape of the dissolving patch and the rate of melting cannot be predicted on a daily basis. Due to snowmelt inhibiting its growing processes, vegetation is unable to connect potentials into a spatially explicit and co-evolutionary matrix.

2. **The Inter-domain Hypothesis (IH):**

According to this hypothesis, complexity consists in the mechanism by which a domaincommunicates with other domains.

Codes and related mechanisms are the expression of complexity, which allow a system to communicate with another system located in another spatio-temporal or organizational domain. To do so, a domain must have a code to be able to convert patterns and processes that have peculiar intra-domain characters.

3. **The Connection Hypothesis (CH):**

The present-day world is becoming more and more connected. This means that energy and information turnover are growing. It also means a rapid exchange of information among the systems. We recognize that connections are important to maintain a system, but a system exists only if the self-regulating units persist.

On the systems' equilibrium and survival, this has a number of effects.

Hierarchy theory and the structure of the landscape

In landscape ecology, hierarchy is a highly helpful framework for examining a variety of patterns and processes at many levels of spatiotemporal scales. Considering complexity as an intrinsic attribute of a landscape, the hierarchy explains how components, localized at a certain scale, are in contact with other components visible at a different scale of resolution (Fig.1).

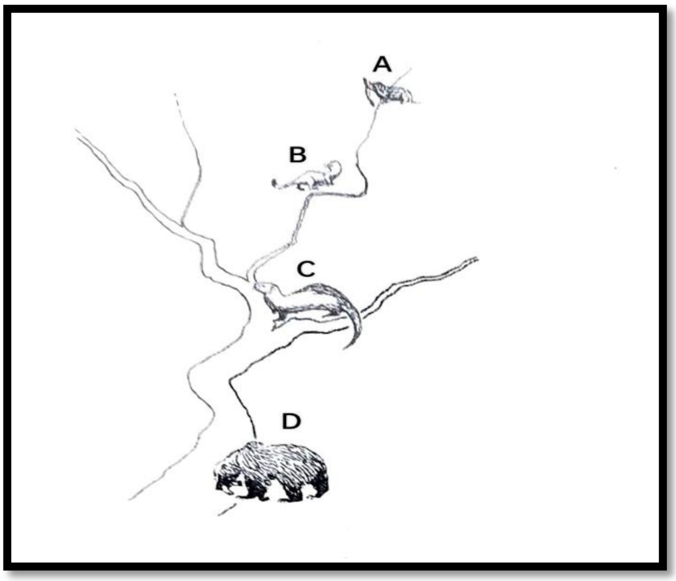


Fig 1: In a complex system, organisms and processes may be structured in a spatial and functional hierarchy. In this case, different-sized mammals are associated with stream order (Reff. Harris 1964)

The hierarchy theory considers a system as a component of the larger system which, in turn, is composed of subsystems. Moving from one level to another of the system, the characters of the phenomena change. Landscape classification is one example of a hierarchical framework moving from ecotope across micro-, meso-, macro and megachores. The complexity of a system can be decomposed in vertical and horizontal structures.

Vertical Structure: Assuming a vertical structure, we expect behaviour to occur at a slow rate.

For example, leaves respond very quickly to light intensity, increasing the photosynthesis, but the grow of a tree is represented by the integration of short time events.

Horizontal Structure:

The horizontal structure of a hierarchical system is composed of subsystems or holons. Holons may also be considered as an interface between the parts and the rest of universe. Every holon is a part of a higher level holon but can be considered as an ensemble of units itself. The bounds of holons may be visible and tangible as the border of a forest or intangible as the distribution of a population (Fig 2).

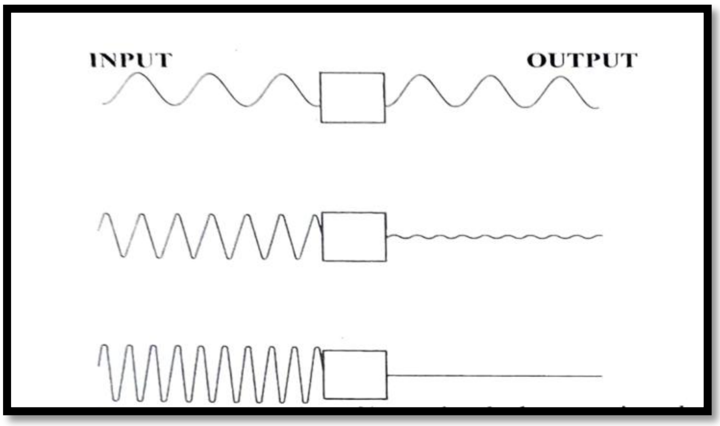


Fig 2: Changing of input signal when crossing a hypothetical constraint. Low-frequency signal crosses the box maintaining the characters unchanged; increasing the frequency in input produces a smoothing in the output (Reff. O'Neill et al. 1986).

Allen & Hoekstra (1992) distinguish five interrelated criteria ordering higher and lower levels:

1. Stronger connections within the component of an organism exist.
2. Relative frequency represents the number of time in which an organism repeats a behavior. The frequency is determined by an internal clock.
3. Context represents the environment in which a lower level is contained.
4. Containment: the higher level behaves more slowly than its parts, in which the whole is the context of the parts.
5. Constraint. The constraint may be considered as the limiting factor of a level.

Percolation Theory:

This theory formulated to study the behaviour of fluid spreading randomly through a medium (Stauffer 1985), In the diffusion process, like the irregular thermal motions of molecules in the liquid, any diffusing particle can move and reach any position medium. In the diffusion process, like the irregular thermal motions of molecules in the liquid, any diffusing particle can move and reach any position in the medium.

A percolation threshold marks between finite regions in which fluid remains when the percolation threshold pc is < 0.5928 (also called critical probability) or the fluid crosses the lattice connecting every molecule of fluid with the others (probability) > to pc.

The systems source sink:

A source is a population in which births exceed deaths and emigration exceeds immigration.

At the other end, a sink population has a negative balance between offspring and death and juvenile production does not have the capacity to compensate for the adult mortality. In the absence of immigration, a population sink would face extinction.

The source-sink paradigm was developed by Pulliam and Dias as a demographic model, but it has been conceptually enlarged in recent years. A source patch is defined as a place harboring a source population and a sink patch as the habitat occupied by a sink population (Fig 3).

Ecological models must consider both the spatial dimension of a species' habitats and the inter-relationships between individuals and subpopulations. In landscape ecology, this paradigm is very helpful in explaining how individuals are distributed differently throughout the mosaic. It is closely related to the idea of a metapopulation because it shares conditions with other occupied patches and human interaction.

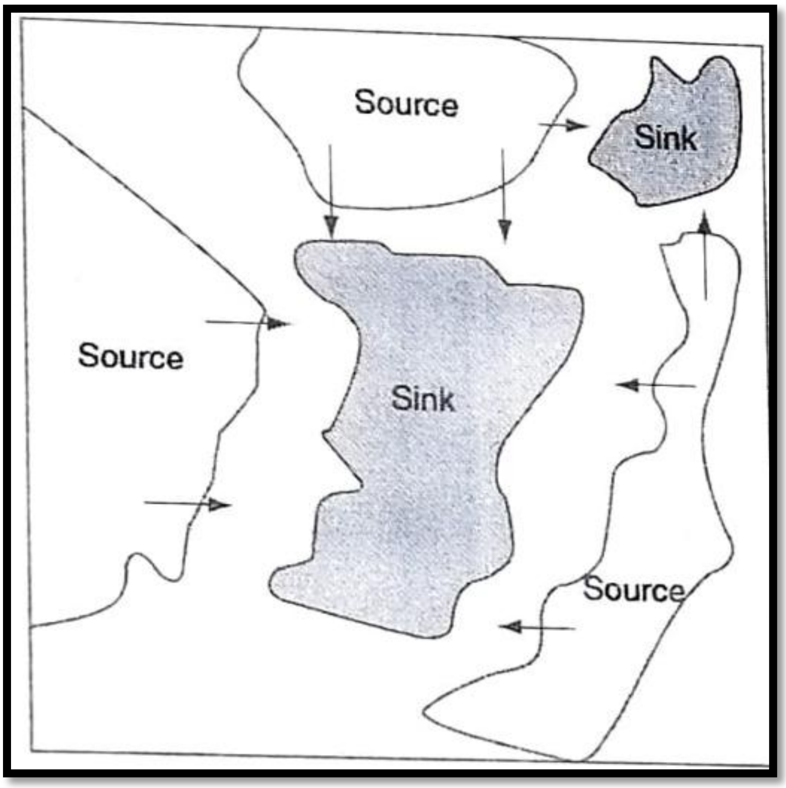


Fig 3: A representation of a source-sink model. Arrows indicate the migratory flux from source to sink areas (Reff. Farina 2006)

The quality of a patch is largely controlled by the size of the patch. In larger patches. Pro-capite production is larger and then the source effect more evident. The reduction of source patches by fragmentation may represent a serious effect for the survival of a population.

Using a demographic model coupled with a spatial (mosaic) model it is possible to study the behaviour of wood mice. This species has been found to fluctuate along the seasons with a early spring-late summer dilution from edges to croplands. This could have strong implications in pest management (Fig 4).

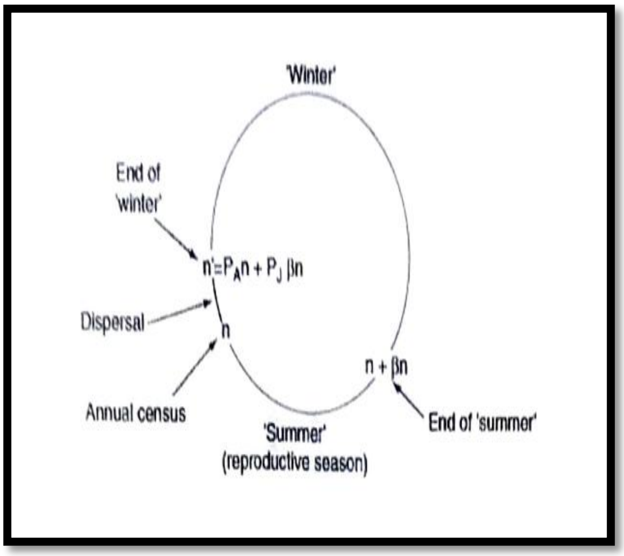


Fig 4: Demographic model in which at the end of the reproductive season n+B individuals are alive and B is composed of adult and juvenile individuals. The survival of an animal after a breeding season is determined by adult survival probability PA and juvenile survival probability B (Reff. Pulliam 1988).

- **Implication of source sink model:**

The existence of source and sink populations has serious consequences for species conservation. Its most important implication is the fact that only source populations guarantee long-term species survival (Dias 1996). In turn, sink populations are in principle not necessary for species survival.

- **Pseudo-sink:**

Watkinson & Sutherlands (1995) coined the term pseudo-sink to illustrate the situation in which there are two habitats, of which one is more favorable and another less favorable but with good carrying capacities. The poorer habitat is overpopulated by the fact that birth/death.

- **Sink vs Pseudo-sink:**

The difference between a true sink and a pseudo sink is that if the sink is true, then the population goes extinct if the immigration rate declines, but in case of a pseudo-sink the population will decrease if the immigration is not active but remains all though some decline is expected.

- **Traps:**

In some cases, habitats appear extremely favorable to species although they have no capacities to assure enough conditions for a full successful reproductive cycle.

Table 1. Summary characteristics of variations on the source-sink dynamics model.			
	Source-sink	**Source-pseudosink**	**Ecological trap**
Source patch (high quality habitat)	Stable or growing Attractive Net exporter	Stable or growing Attractive Net exporter	Stable or growing Avoided (or equal) Net exporter
Sink, pseudo-sink, or trap patch (low quality habitat)	Declines to extinction Avoided Net importer	Declines to stable size Either Net importer	Declines to extinction Attractive (or equal) Net importer

<u>Source-sink dynamic and conservation issues:</u>

Donovan et al. (1995) have prepared a model to verify the effect of fragmentation on a source-sink system of neotropical migrant birds. According to this model, the fragmentation of breeding habitats and common patterns in boreal regions has a more significant effect in small habitat patches than in larger, core habitats.

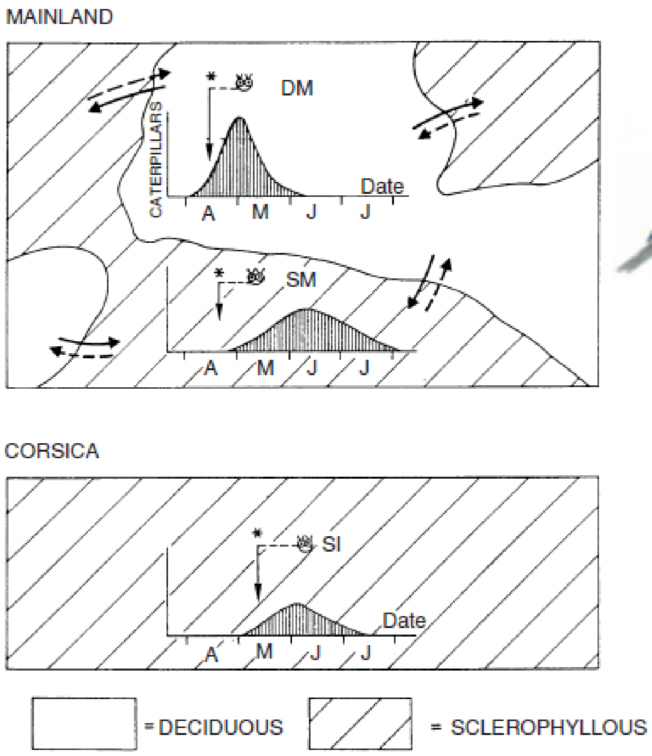


Fig 5: Example of source-sink system of bluetit (*Parus caeruleus*) in France and in Corsica. In mainland broadleaves, the laying time is synchronized with the food

evergreen forests. In Corsica,this species, genetically isolated by the mainland population, has a laying deposition date synchronized to evergreen forests (Reff. Blondel et al. 1992).

TOPIC 2 (b) Scale and landscape, Scaling the landscape, Change of scale perception. Importance of parameters at different scales,

SCALING THE LANDSCAPE-

Scaling the physical processes like runoff, the spatial distribution of plants and the behavior of animals is an attitude that considers the ecosphere as a hierarchical system in which patterns and processes moving from one layer to another modify their properties. (Steinhardt & Volk, 2002). Most landscape ecological research is posed from a scale of a few meters up to thousands of kilometers, across which most of the ecological processes are completed. The same appears for the temporal scale often considered from the seasonal resolution as in the study of dynamic of metapopulations to the millennia of the biome modification. System is functioning across a variety of scales and, when observed at one resolution, we perceive some characters filtering out most of the noise due to the close levels (sub and upper levels) of the entire system's organization. Different methods of spatial statistics can be successful in studying the variation of processes according to the scale; for instance, fractals, semivariograms, correlograms and spectral analysis.

Patchiness and variability are exhibited by every population across a broad range of scales and such a system is strategic for maintaining ephemeral or competitively inferior species which depend upon the local modification of resource availability and inter-specific competition. The recent use of remote sensing technologies enables us to investigate local processes across a broad range of scales with the possibility to find the best resolution.

EXAMPLES OF SCALES IN LANDSCAPE AND IN ECOLOGY-RELATED DISCIPLINES-

a) **Scaling the quaternary landscape-** Delcourt&Delcourt (1988) define four levels of the scale related to landscape ecological issues to study the quaternary landscape ecology:

Micro-scale dominion- This scale considers a time lag from 1 to 500 years and a space from Ima to 106ma. Scientists working with this scale are geomorphologists, plant succession and animal ecologists and planners. Disturbances like fires, wind throw and clear cutting are interesting at this scale Geomorphic processes as soil creep, movement of sand dunes, debris avalanches, slumps, fluvial transport and exposition, cryoturbation and biological processes are characterized by cycles of animal populations, gap-phase replacement in the forests, succession after abandonment. In forested landscape fragmentation, increase of ecotones and change in coridor availability.

Mesoscale dominion:-: the mesoscale dominion extends from 500 yrs to 10,000 yrs and in space from 106 to 101o m2. In this period are the events that range from the last interglacial interval and on a space from the watershed on second-order rivers. In this domain, the cultural evolution of humanity occurs.

Macroscale dominion:-the macroscale dominion extends from 10,000 yrs to 1,000,000 yrs and with spatial extension from 1010 to 101n m2. In this dominion, the glacial-interglacial cycles occurred and speciation and extinction operated.

Mega-scale dominion:- this dominion extends from 106 yr to 4.6 billion years, with an extension>1012 m2 covering the American continent and interacting geological events like the plate tectonics movements.

b) Scaling patterns: The catchment scale

This scale is very popular in this period. It seems to be a very promising dimension in which the fluxes of water and elements link the different components of the systems. Disturbance regimes such as agricultural intensification, afforestation and fires can be monitored using the chemical composition of streams and underground and surface waters. Especially small catchments can be adaptable components to study pollution, land management activity and environmental changes.

c) Scaling abiotic processes: Hydrological processes and scale:

Hydrological processes are principal components of landscape mechanisms. Their dynamics have a dramatic influence on most of the abiotic and biotic processes. They range in eight orders of magnitude in space and time occurring at a wide range of scales from unsaturated flow I m soil profile to floods in river systems of a million square kilometers, from flash-floods lasting some minutes to flows into aquifers over hundreds of years.

Usually, three levels of scale are used in the study of hydrological processes: (a) the lifetime (duration) (for an intermittent process like a flood); (b) the period or cycle (for a periodic process like snow-melt; and (c) the correlation length (integral scale) that represents the average distance of correlation between two variables.

d) Scaling evidence in animals:

Every species perceives the surrounding environment (landscape) in a different way. The movement of a grass stem appears parrossistic for aphides but is not perceived at all by deer. Unfortunately, we often select scales more comfortable to our metrics than to the species, although it is possible to judge the best range of scale at which an organism spends its life (territorial behavior, dispersal movements, food research). The animal behavior interacts with the environmental patterns and processes across several spatio-temporal scales. The fact that organisms have capacities to move across a range of scales is well documented. This capacity is important, considering the complexity of the life cycles of organisms such as mammals (Fig 6).

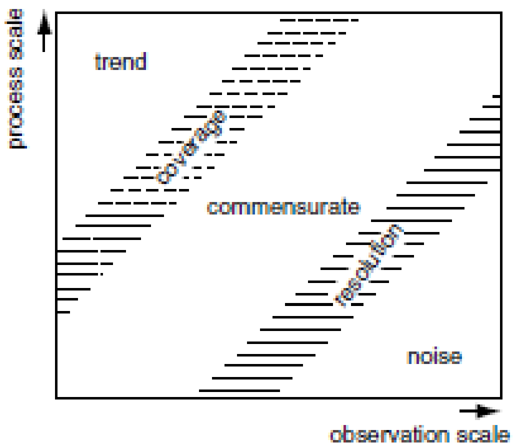


Fig 6 Plotting the process scale with the observation scale creates three regions in the design according to the sampling resolution. If the coverage is smaller than the process measured, the information achieved can be described as a trend. On the other hand, if the process is smaller, then the resolution appears as noise. The intermediate belt appears as a commensurate space (Reff. Bloschl&Sivapalan 1995).

e) Landscape organization and scaling approach

It is a common practice to superimpose a map of emergent characters of a land mosaic (heterogeneity) with the map of distribution of organisms or their emergent characters like diversity. This exercise is full of uncertainty and biases. Two measures of landscape organization are proposed: the alfa organization and the beta organization. Alfa organization measures the degree of deviation from random distribution of the selected feature (such as land use). Beta organization measures the degree of deviation of a spatial distribution ofa property like land use.

Low values of alfa and beta organization indicate a random distribution of potential resources for organisms, and a less metastable system. The modem use of land by agriculture is less coupled with soil type, water availability and nutrient distribution because all are supplied artificially. The result is a system less stable and unable to support organisms operating at the scale at which humans use the land.

The perception of the surroundings by birds changes according to the species considered. It has observed that in midwestern forests, 29% of bird species is most sensitive to local vegetation variables (number of living stems, organic litter depth, percentage of canopy cover, estimated percentage of forbs) while 67% was more sensitive to landscape variables (forest cover, cover area, edge density and mean patch size).

Probable questions:

1. What is Landscape Ecology?
2. Describe the Uncertainty hypothesis of landscape ecology.
3. State the Factors of landscape ecology
4. Describe the Hierarchy theory and the structure of the landscape
5. What is Percolation Theory?
6. What is source and sink?
7. Stae the implication of source sink model.
8. Give two examples of scales in landscape and in ecology-related disciplines.
9. Describe four levels of the scale related to landscape ecological issues.

Suggested Readings:

1. Smith TM, Smith R L. 2006. Elements of Ecology. 6th Ed. Pearson Education
2. Chapman RL, Reiss MJ. 2000. Ecology - Principles & Application. Cambridge University Press.
3. Odum EP, Barret GW. 2017. Fundamentals of Ecology. 15th Indian reprint. Cengage learning India Pltd.
4. Ricklefs RE, Miller, GL. 2000. Ecology. 4th Ed. W. H. Freeman & Company.

Unit XVIII

Landscape Ecology: c) Processes in the landscape: Disturbance, Fragmentation, Landscape connectivity, Corridors, d) Methods in landscape ecology, Spatial data processing, fractal geometry approach, urban ecology

Objective:

As interested in identifying best practice as it is in progressing landscape theory, the Landscape Series particularly welcomes problem-solving approaches and contributions to landscape management and planning. The ultimate goal is to facilitate both the application of landscape research to practice, and the feed back from practice into research.

TOPIC 3 (c) Processes in the landscape: Disturbance, Fragmentation, Landscape connectivity, Corridors

DISTURBANCE

Disturbance is a very common and widespread phenomenon in nature and may be defined as a discrete event along time that modifies landscapes, ecosystems, community and may be defined as a discrete event along time that modifies landscapes, ecosystem, community and population structure, changing the substrate the physical environment and the availability of resources (White & Picket 1985). It can be considered as a basic process, responsible for many other processes like fragmentation, animal movements, local and regional extinction etc.

Every landscape is shaped, maintained and/or changed by disturbance. For instance, disturbances like clear cutting and wildfires have a strong influence on the structure and functioning of many landscapes.

Disturbance occurs in many biotic assemblages, at all levels of organization from individual to landscape. Disturbance combines long-term scale changes with "actuality". The basic variables of disturbance are magnitude, frequency, size and dispersion.

Disturbance is a source of spatial and temporal heterogeneity. At the landscape level, disturbance is related to patch structure and spatial arrangement, determines the fate of patches, their size and duration. Severe disturbances or the lack of disturbances generally have depressing effects on the diversity.

Intermediate disturbance seems to enhance diversity in the systems. Where disturbance recurs more frequently than the time required for competitive exclusion, the diversity of the biological assemblage is maintained (Fig 7).

Disturbance may be produced by abiotic factors such as solar energy, water, wind, landslides or by biotic elements like bacteria, virus, plant and animal competition, etc..

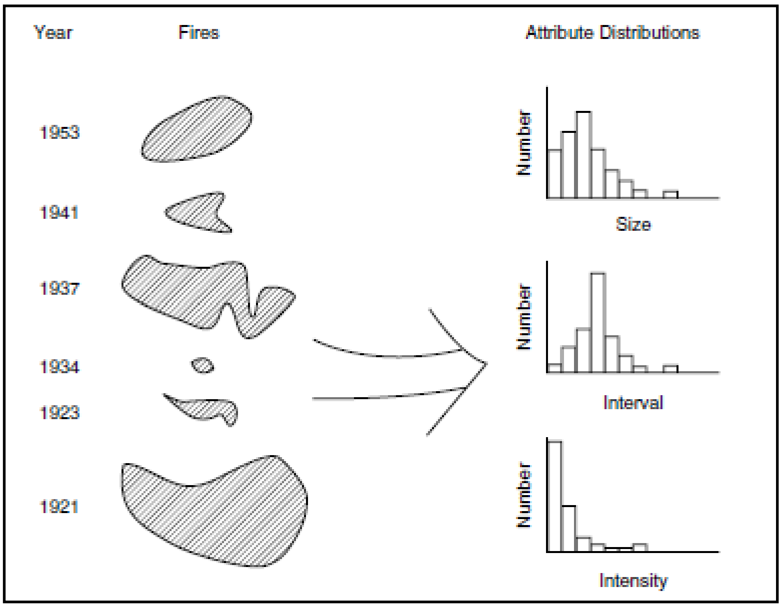


Fig 7. Example of fire disturbance regimes during a recent period. Every disturbance event, in this case fire, has a disturbance patch with different shape and attributes (size, interval and intensity) (Reff. Baker 1992).

[a] Snow cover, an abiotic disturbance

Due to the high climatic constraint, the vegetation cover in alpine type landscapes is extremely patchy. Snow cover controls the distribution of many species of plants, reducing the length of the growing season. The distributions now are strongly conditioned by topography and wind patterns. But exposed ridges experience low temperature in winter and animals like moles, gophers, voles, etc., responsible for the fine-scale mosaic, are also conditioned by snow accumulation. These species find refuges in snow accumulation and protected rails for soil exploration.

In winter, when the soil is covered by snow the snow vole (*Microtus nivalis*) often builds its nest with dry grasses and moss on the surface of the soil and digs tunnels in the compacted snow to search for food.

Plants react to snow cover in different ways. Some species escape deep snow cover (for example, *Paronychia pulvinata*), others are mainly localized in deeps now cover (for example, *Sibanda procumbens*) and others show no precise snow interaction, spanning a broad range of snow depth. These plants are good indicators of plant association and, therefore, can be used as indicators of landscape scale plant community distribution. Snow accumulation has an indirect effect on vegetation and the circulation of nutrients in the soil during the spring snow melt. This process is extremely important in alpine regions, where plants suffer from nitrogen and phosphorus deficits.

b) Human disturbances

Human disturbance is not different from natural disturbance but with some significant differences, especially in extension, severity and frequency. These last factors make all the difference. Forestry, agriculture, development, infrastructures are some of the disturbances that human activity can produce on the landscape and at larger scales in regions. Human-environment interactions are distributed worldwide, and we can emphasize that all parts of the planet are affected by such a dominant presence. Naveh (1992) utilizes the term "total human ecosystem" referring to the Earth. The disturbance regime due to human activity is expanded by technology to a broad range of spatial-temporal scales, with effects ranging from the deepest oceans to the highest mountain ridges. The capacity of the landscape to incorporate human disturbance is in many cases outside the limit and disturbance processes are transformed into stressful processes, which reduce the diversity of the ecological communities.

In some cases, human disturbance has multiplicative effects both on landscape patterns and population dynamics. An example is from stream ecology. Streams have longitudinal as well as lateral dynamics, influenced by the watershed quality and in-stream modifications. Fishes living in such habitats are size-structured vertebrates. This means that a population is composed of differently aged individuals with a broad range of sizes. For every size class the provided habitat is specific. Any alteration of stream structure has a specific effect on the different age-classes of fishes. The alteration of stream dynamics and structures by human use of the land produces consistent effects on the composition of fish populations.

Deforestation for logging represents a major source of landscape disturbance, especially in relatively pristine areas. A study demonstrates that environmental evaluation is scale dependent and that a multi scale approach can overcome the difficulties of environmental assessment. Often, a disturbance regime is the result of cumulative effects. The fact has increased the fragmentation of the vegetation cover that appears more patchily distributed and favored by the lack of wildfires.

Often, the attributes of the human disturbance differ from the attributes of à natural disturbance. For instance, a fire along a Mediterranean coast produce intentionally or by human "lack of attention'" is not different as a process from a wild fire, but this fire, if repeated at every season (improbable in wild conditions), can produce stress on vegetation, reducing vegetation, cover, increasing soil erosion, etc.

Human activity is modifying the face of the Earth, reducing natural vegetation, animal communities, and exemplifying landscape mosaic. There arrangement of natural systems according to human needs, especially if carried out by burning fossil oil, dramatically interferes with the ecosystem dynamics and landscape mosaic structure. At the community level, an urban area can have a diversity peak, where urbanization is moderate.

Human-caused disturbance has recently been considered by Frid& Dill (2002) as a form of predatory risk. In fact, there are several evidences that human activity produces a non-lethal disturbance on the behaviour and there productive success of animals. Predatory pressure and disturbance produce similar trade-offs to avoid risks and perform other functions (activities) like feeding, mating or parental caring. Predatory avoidance is a function that requires energy and this activity reduces the energy available for other functions.

Human activity disturbs wildlife in different ways, by producing loud noises like the shot of a rifle or the sound of a horn or the intrusion of visitors into the animal ranges. Landscape features can reduce the cost of this disturbance (predatory -risk hypothesis) by reducing the distance at which animals react, moving from a site and interrupting a function.

For instance, in some amphibians, safety is postponed for mating access. In a territorial display, a European robin (*Erithacus rubecula*) reduces the distance from feral cats, dogs and humans. But organisms forced by the disturbance to select less favourable areas can experience a rapid decline in intraspecific competition or an increased predatory pressure.

Human disturbance can produce unexpected effects; for instance, it can facilitate the entrance of invaders into a community. This is the case *of Chaerophyllum aureum*, a species that is common in meadows in Pyrenean valleys. The genetic variability that is the main cause of diffusion of this species is increased by the human practice of hay production, as reponed by Magda &Gonnet (2001) (fig 8)

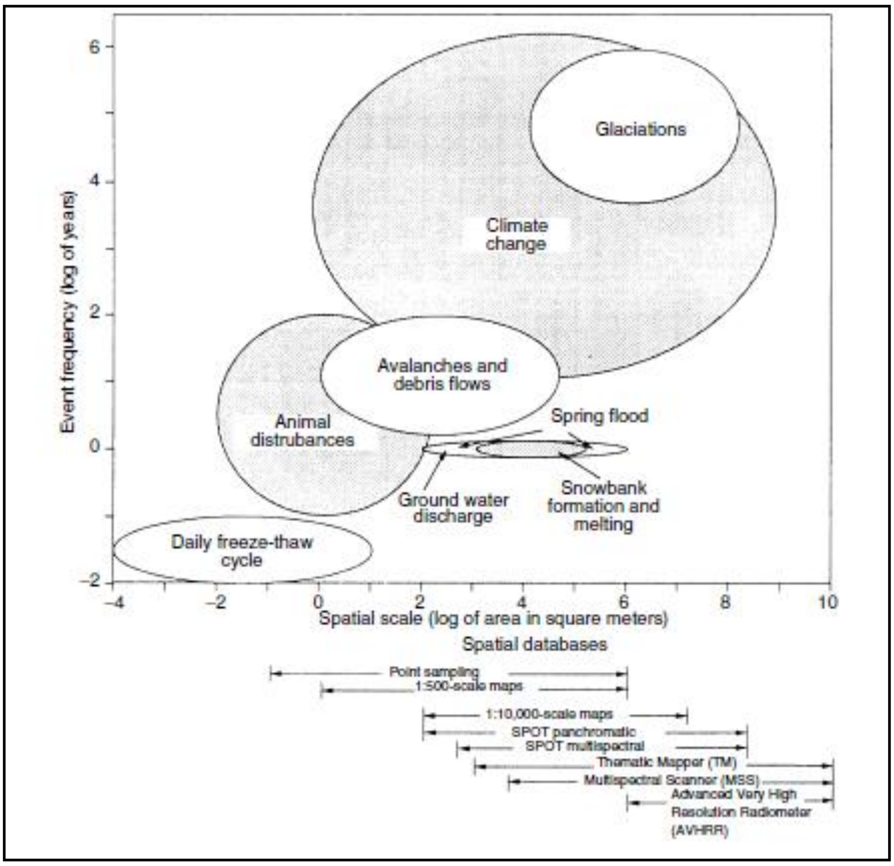


Fig 8.Frequency of the disturbance and the spatial scale of resolution in cold climates. The available data types are indicated at the bottom of the figure as examples of the application of a multi scale approach ranging from data input by field survey (quadrat plots) to remote sensing techniques (Advanced Very High Resolution Radiometer, AVHRR) (Reff. Walker et al. 1993).

c) Gap disturbance in forest

Gaps are small openings in forest cover due to local events such as tree fall and are not generally a random event, but some sites are more likely to have gaps than others (Porter et al. 1 994). Most of the species that live in old-growth forests require gaps to reach maturity. Across the forest, the gap density is constant, but these authors have found that along a catena, gaps are more abundant in the middle part, while in the upper and lower slopes, gaps are less frequent. The regeneration occurring after the formation of a new gap plays a fundamental role in structuring forests and maintaining species diversity.

Gaps are inhabited by different species of organisms in comparison to the forest understory. Large, infrequent blow downs can modify the structure of forests favoring insect pests, secondary succession and fire propensity. Such disturbances produce only a partial loss of over story trees, and most of the dead snags and fallen woody material is retained. Edges between blow down and intact forests are typically lower-contrast edges.

Large forest disturbances such as hurricane Hugo can change the structure of bird assemblage in old gaps and new forest disturbances. Wunderle (199S) has found that the major effect of the passage of Hurricane Hugo on bird assemblage in a Puerto Rican forest has been the loss of distinctiveness between the bird assemblage living in the gaps and birds living in the disturbed understory.

According to this author, probably many years will pass before the gap and understory become distinct in structure and resources in forests where large disturbances are rare, the gaps created by the killing of one or a few canopy trees plays a fundamental role in structuring the entire forest. Gaps are particularly evident in the changing phase from mature to old growth forests.

A tree that dies is considered a “gap maker” because it creates the gap. An edaphic gap must be distinguished from a tree gap because it is produced by edaphic conditions such as stream courses or thin soils. In the forests of British Columbia, Lertzman et al. (1996) have estimated that in the absence of a large disturbance such as fire, windstorm or insect diseases, gaps created by a regime of small-scale, low-intensity disturbances are responsible of the turnover of these forests in between 350 and 950 years. Where gap disturbance is common, interestingly, is about 56% of the forest area investigated. Most of the gaps are produced by more than one dead tree. Some gaps (a third) were found to be produced by edaphic factors like stream courses (Fig 9).

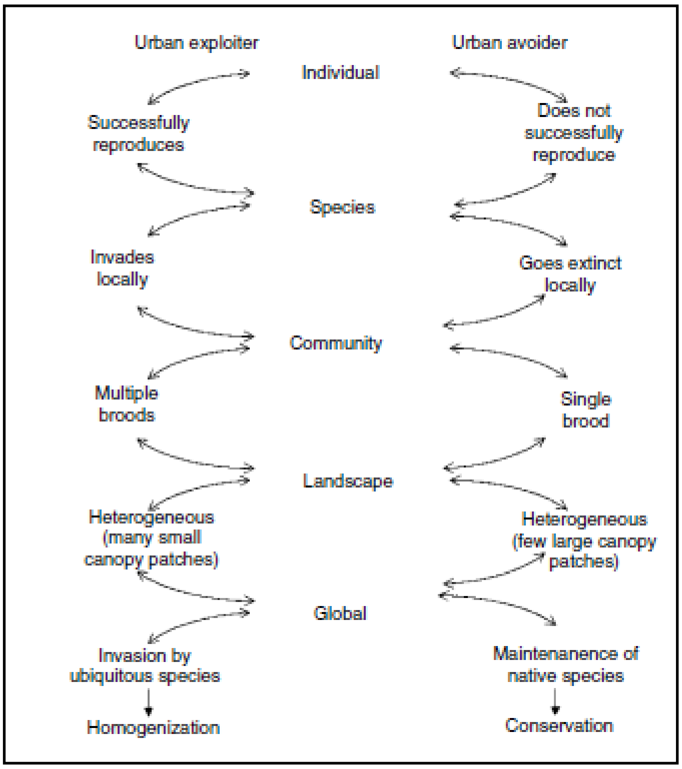


Fig 9. Conceptual model used to illustrate the relationships of birds at different levels of aggregation (from local to global) and the urban sprawl according to the attitude of species to exploit or to avoid an urban environment (Reff Blair 2004).

d) Gaps in savanna

Recently, Belsky & Canham (1994) have discussed the structure and function of savanna trees in a matrix of grasslands comparing forest gaps with savanna trees. This approach seems very interesting, although in some cases, it is intriguing. Tropical savanna dynamics may be explained in terms of gap dynamics. Trees and shrubs are the "gap" in the grassland matrix. In savanna "gap", a gap is initiated by tree seedling establishment and growth. The physical conditions under savanna trees are different compared with the surrounding open savanna, like gaps in a forest environment. During the wet season, the soil under the trees is dryer, but later in the season; the soil is wetter under trees due to reduced evaporation and respiration in the shade and a cooler temperature. It is well known that under savanna trees, the soil is richer in nutrients due to root transportation, manure deposition by wild and domestic animals and by a less stressful bacteria cycle (Fig 10, 11).

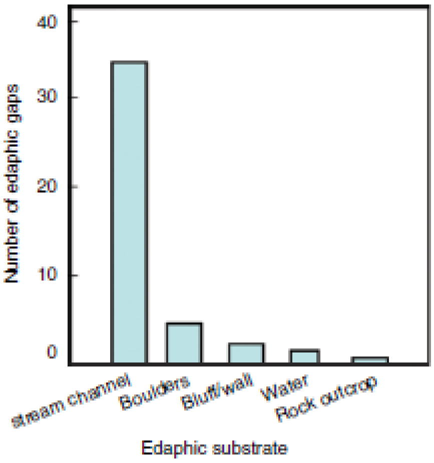


Fig 10 Frequency distribution of edaphic gaps distinguished by physiographic causes (Reff. Lertzman et al. 1996).

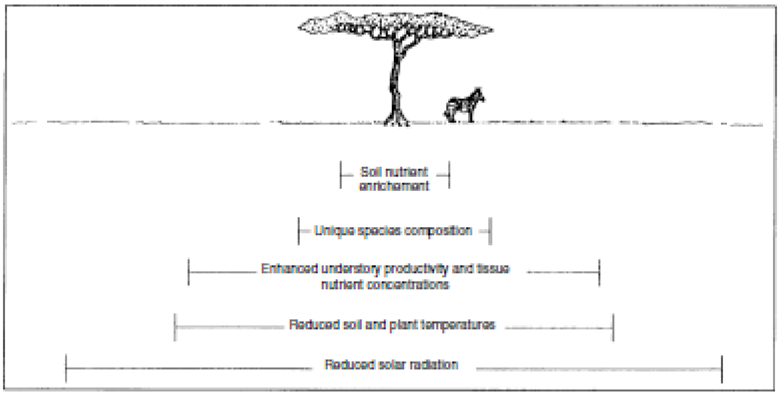


Fig 11. Effects of isolated trees in tropical savanna (*Acacia tortilis*) in Tsavo National Park, Kenya (Reff. Belsky&Canham 1994).

e) Fire disturbance in landscapes

Fire is one of the most important shaping agents in landscapes. It removes the unrecompensed biomass and creates nutrient fluxes by ash deposit watering, contributing to the ecologically rejuvenating qualities in forest ecosystems(Moore 1996). In a dry continent like Australia, fires have played an important role in shaping vegetation mosaics and fauna distribution. In desert areas, fires produced by lightning create a complex mosaic of burned-unburned areas that favour several species of animals like lizards (Pianka 1986). Recent studies and simulations conducted by Haydon et al. (2000a,b) in the Great Victoria Desert have emphasized the role of wild fires as main perturbation agents. Fire size is influenced by wind direction, shaping scarring areas into an oblongate form. Perimeters of larger fires are more complex than smaller fires. Large fires have

more tongues than smaller fires, according to the wind direction. Fire can be considered fractal objects (see Figure 4.9. Older patches are more prone to burning due to a major accumulation of biomass.

Fire has been utilized as management tool to manipulate the ecosystem since Mesolithic times (Naveh 1 990, 1991; Grove & Rackham 2001; Blondel &Aronson 1999). If the release of nutrients is well documented, the role of charcoalin the soil appears neglected. Charcoal has the capacity to retain water and a sandy soil can behave like clay if added to charcoal. But other functions have been recently recognized for charcoal as a sink for phenolic inhibitors. In this way, both plants and microbes are stimulated. The effects of fires on vegetation cover depend on a plethora of concurrent factors like fire history (severity, recurrence), climate, topography and dominant type of vegetation.

Fire, when associated with grazing, can represent a dramatic disturbance in ecosystems. As reported by Bailey & Whitham (2002), large crown fires in Arizona affect aspen (Populus tremuloides)regeneration and arthropod species and abundance. These effects largely depend on fire severity and on elk grazing pressure. Fire severity per se has no direct effects on arthropod richness and abundance. But moderate severity and moderate levels of elk browsing assure 30% greater richness and 40% greater abundance in arthropod communities. On the contrary, high severity fires and high levels of elk browsing reduce diversity and abundance by 69% and 72%, respectively. The study of fire occurrences during long period of time is recommended by Rollins et al. (2002) as a historical baseline for fire management in wilderness mountain complexes.

f) Pathogen disturbance

Less attention has been reserved for the role of pathogens in shaping and structuring forests. Pathogens influence forests at different ranges of spatial and temporal scale. Forest diseases occur in patchy distributions across the landscape (Lundquist & Klopfenstein 2001) and pathogens reflect their genetic variability and the landscape heterogeneity. This creates a disease prone land mosaic across the entire forest landscape. Some pathogens like Brunchorstia pinea, responsible for Scleroderriscancerin pines, are more active in cold temperatures with more impact on stands occurring topographic depressions and forest openings whereas the cold air accumulates. The cancer of sweet chestnut has accelerated the change of the landscape in the southern Europe, in combination with land abandonment. A great area occupied by this type of orchard has been modified in a short time by cutting off of diseased plants.

Pathogens play a fundamental role in the formation of gaps in mature and healthy old-growth forests. Patch-phase processes of disturbance create the conditions for landscape heterogeneity, enhancing plant diversity and resources availability for plants and animals. Pathogens also change the composition of forests, increasing the unevenness of stands. Knowledge of pathogen cycles is essential t to efficient and accurate management off forests (Castello et al.1995).

g) Animal disturbance

Digging and grazing are the most common disturbances produced by animals (herbivores). This disturbance severely affects the distribution and structure of vegetation (grass, forb and shrubs). In forested area, grazing prevents the growth of seeds. Trampling associated with grazing modifies the composition of natural vegetation and reduces the inter specific competition creating patches of high diversity but this disturbance is often quite complex (Hobbs and Mooney 1991).In natural and livestock-grazed prairies, the deposition of urine is a cause of local disturbance that produces a complicated mosaic at a larger scale. This mosaic depends mainly on the density of grazing wild or domestic animals.

Steinauer & Collins (1995) tested the effect of urine deposition in differently disturbed grasslands. Plant abundance increases after urine deposition, but A and B diversity displayed local behaviour, mainly due to litter depth. This biomass accumulation attracts more herbivores and the effect of urine is expanded in the neighbouring environment.

Finally, the grazing intensity in such patches has a much deeper effect than urine deposition alone. This seems a good example of disturbance overlap that can reinforce the reaction of the environment.

FRAGMENTATION:

Fragmentation can be considered as the “negative image” of connectivity. These processes have a strong influence on the dynamics and fate of material and energy moving across a landscape.

Loss of native plant and animal species, invasion of exotic the species, increase of in soil erosion fragmentations and decrease of water quality are some of the consequences of habitat fragmentation.

Fragmentation is one of the most severe world-wide processes depressing biodiversity. It moves at an alarming rate around the world, reducing large forest cover as natural prairies. Clear cuts and roads dramatically increase the fragmentation effects on forest cover, and especially roads are important agents of forest cover changes.

Fragmentation is a process that presents a negative influence on many species of plants, animals and ecological processes in landscapes as well a as in seascape. Reducing the size of fragmented blocks decreases the density or populations and meta-populations and the extinction risk grows

Fragmentation means geographic isolation and, after extinction, the probability of recolonization strongly depends on the distance of the fragments from the main core and on the quality of the surrounding habitat.

In tropical areas, forest fragmentation affects pollen and seed dispersal, with modifications in gene flow (Hamilton 1999). Species sensitive to the edge (interior species) can reduce in abundance or in pairing success. Large predators disappear, producing outbreaks of foragers viz; deer. This last effect allows further environmental degradation and disturbance.

Fragmentation is often interpreted by the general framework of the island biogeography theory (MacArthur & Wilson 1967) but area size and isolation factors taken into account by this theory are not enough to explain the effect of fragmentation in habitat islands. If the fragmentation is simply consideredas the s size of isolated patches, this approach appears be uninformative.

Fragments cannot be considered as true islands; in fact, the surrounding habitat is often not completely hostile to the species.

Other factors such as connectivity, presence of ecotones and corridors, and the metapopulation structure have to be taken into account, especially when fragmentation is studied on a landscape scale.

Fragmentation can be considered a continuum process, and according to a landscape perspective, matrix and patches are the elements that have to be uses or considering a landscape, fragmented or not.

Fragmentation is perceived in a different for the same species way according to the different species and also it may be different according to the seasons. Thomas (2000) has found that butterfly species with intermediate dispersing capacities are more affected by fragmentation in comparison with sedentary or highly-vagile species.

At the edge, the behaviour of species is different. For some species, edges are highly suitable habitats, but others avoid them. Nest predation can be higher at the edges and this has a big influence on the suitability of the patches in a fragmented landscape.

Fragmentation is really dynamic process. The human disturbance regime as well as natural disturbances produce fragmentation but often the recovery of vegetation cover masks or mitigate this process. In other cases, the fidelity of some species to a site reduces the effect of fragmentation.

Fragmentation dynamics are strongly influenced by human decisions and by land policy. Fragmentation can be increased not simply by reduction of patch size but also by the isolation of patches produced by large roads. Severe effect of highways on the distribution of birds in an agricultural matrix. In particular, forest bird seems more sensitive to the presence of such barrier. Noise produced by traffic does not seem the only factor impacting bird presence. Probably, other factors like the decrease of connectivity between the forest fragments are also important.

Fragmentation in tropical areas strongly affects the survival of large trees, which are unusually vulnerable. Large trees, as argued by Laurance et al. (2000), are more prone to uprooting and breakage near forest edges where wind turbulence is frequent and higher. Large trees are frequently invaded by lianas (woody vines) that benefit from light and nutrients but which reduce the survival of trees. But the higher exposure to sunlight and evaporation also contribute to tree desiccation. The reduction of large trees affects fruit production, flowers and shelter for animal populations.

Scale and patterns of fragmentation

Fragmentation is a scale-dependent process. Fragmented vegetation can have a different spatial arrangement and produce different effects on other ecological processes.

To describe the dispersion of fragments in an area, it is necessary to consider different attributes of the fragments such as density, isolation, size, shape, aggregation and boundary characteristics.

The isolation of patches increases geometrically as the density of the fragments decreases. The fragments become smaller and more influence is received from the surrounding matrix. If fragments are aggregated, their isolation is smaller than in conditions of equi-dispersion.

We have **different types of fragmentation** . According to Lord &Norton(1990)

- **Geographical fragmentation:** when an intact area is divided into smaller intact fragments, we have a "geographical fragmentation". This process has received a lol of attention from conservation ecologists for its implications for nature conservation. This pattern can be analogous to a coarse-grained landscape.

- **Structured fragmentation**: we can have fragments at the scale of Individuals or small plots. It is the case with small remnants of native vegetation embedded in an alien matrix and the fragmentation is considered ns "structured fragmentation" and is analogous to "fine-grained landscape. Fine-grained fragmentation generally presents patches close to each other and the contrast between patches and matrix is shallow, creating a pseudo continuum.

While geographical fragmentation is associated with forest ecosystems, structural fragmentation may be associated with a broad range of conditions. Fragmentation effects on organisms largely depend on the scale of perception of the focal species. Generalists are less affected by fine-grained fragmentation than specialists.

Fragmentation increases the vulnerability of patches to external disturbances, for instance wind storms or drought, with consequences on the survival of these patches and of the supporting biodiversity (Nilsson &Grelsson 1995). The scale of fragmentation has a direct impact on organisms. Large fragments maintain a good subset of species but small fragments have only few species, generally the more generalist ones. Thus, specialists disappear from smaller patches when the fragmentation is at a fine-scale. This could be the reason for a sufficient diversity in temperate regions facing a fine-grained fragmentation when compared with the more specialist species of tropical areas.

Fragmentation reduces the size of woodlots but also the habitat quality. For instance' increase of woodlot density in St. Lawrence Valley (Quebec, Canada) with the increase of agriculture, but the size of woodlots was observed to be decreasing.

Fragmentation was found to increase, moving from traditional dairy agriculture to more intense cash crop agriculture .

Large fragments have more species, are less disturbed and lower road access than smaller ones. Large fragments are uncommon or rare and their importance is high for nature conservation issues.

Fragmentation depends on human use but the human use is also affected by the fragmentation rate. This is relevant in regions such as the Mediterranean, where several changes in land use occurred across the centuries, modifying the behaviour of people according to the new characters of the fragments.

Fragmentation can be observed at any scale, and tree-fall gaps are one Important factor increasing heterogeneity and fragmentation. Tree-fall gaps can be considered a distinct habitat in a forest differing structure (e.g., foliage density, tree size distribution), plant species composition, resource abundance and microclimate conditions.

Community composition and diversity in fragments:

Small woodlots have less species than the biggest once and there are more generalist in small rather than in larger Woodlots. More specialized species increase with the increase of the Woodlot area.

Birds breeding in the interior forest and wintering in the tropics are more affected by reduction (fragmentation) of forest habitat. The area effect is disputable according to neighbouring habitat. In fact, if there are suitable habitat around a woodlot, these habitats could be incorporated by some species, but if the woodlot is separated by agriculture fields, in this case, the habitat constraint is stronger and the isolation is higher, negatively affecting the presence of species (Fig 12)

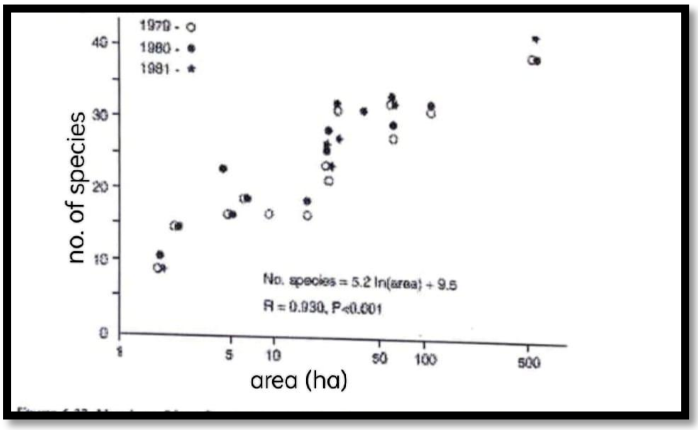


Fig 12.number of breeding species plotted as function of natural logarithm of an area of woodlot in east central

Habitat requirement for sensitive species is not limited to area size but also to surrounding characters.

Significance of habitat fragmentation that is not limited only to the size of patches but also to the mean shoot diameter.

ln boreal European forests, landscape fragmentation has been observed to negatively affect the breeding success of black grouse (*Tetraotetrix*) and capercaillie (*Tetraourogallus*) either in terms of forest rarefaction or in terms of destruction of older forests (Kurki et al. 2000).

Mosaic context is a further element that can reduce or mitigate the effects of fragmentation. Lower nesting and pairing success observed in small fragments were probably caused by permanent dispersion rather than by fragmentation increasing mortality.

Decline appears more in rare species than abundant species, isolated species are more affected by fragmentation than species that are not isolated. The body size does not seem to be correlated with fragmentation effects and that among the species that decline; predators are the group that decline most. Finally, taxonomically-related species respond differently to fragmentation processes.

Species, guilds and fragmentation:

Some species are sensible to habitat size, these species are called "area-sensitive" ·

Fragments had less, rare and dispersed species. This difference was particularly evident when 1 ha fragment was compared with undisturbed forest.

Fragmentation at the level of species, the results may be completely different. Species sensitive to habitat fragmentation are less efficient in moving and colonizing new habitats, with a consequently lower dispersal ability . Birds of the African tropical understory forests are particularly sensitive to fragmentation (Newmark 1990). Rare and forest interior species of birds are more adversely affected by habitat reduction.

The bird decline is fully documented and secondly because the effect of fragmentation in large part depends on the biogeography of the species and on the complexity of the forging structure. Fragmentation produces changes in the organism distribution and relative patterns. Habitat loss and fragmentation affect dispersion more than demography. In homogeneous habitat, demography is lower but stable during a 10 generation period. The dispersal drops dramatically in fragmented areas (Fig. 13).

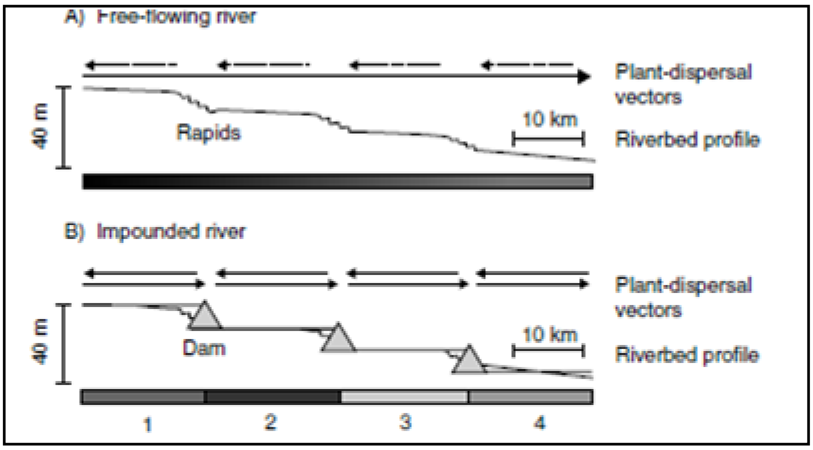


Fig 13. Flora in impounded rivers is hypothesized to local organization and separation when compared with free flowing river (Reff. Janson et al. 2000)

<u>Fluctuating Asymetry:</u> is a pattern of bilateral variation that is normally distributed around a mean of zero in morphological traits where symmetry is the normal state. The appearance of asymmetry is linked to environmental instability and is used as an indicator of environmental quality but also of genetic variance in populations or in individual quality. For instance, leaf asymmetry of the holm oak (*Quercus ilex*) from SE Spain has been found to increase with the increase of stress dependence.

<u>Landscape Connectivity:</u>

Landscapes are heterogeneous across a broad range of scale. It is characterized by the presence of patches with different isolations from patches of the same types. Three important concept can address the problem of patch isolation: connectedness, connectivity and corridors.

<u>Connectedness or proximity</u> is the degree of physical distance between patches.It is structural (descriptive) attribute of a landscape mosaic and can be mapped .Thus the matrix is the most connected element of the landscape.Generally,connectedness to other elements of landscape as woodlots, hedgerows,riverbedsetc. The opposite situation is called isolation.

In some rural areas, the hedgerow network is the most connected component after the field matrix. For instance, woodland connectedness (potentially) plays a fundamental role for species that needs tree cover for their movements. For instance, the increase of woodland connectedness after land abandonment has favored the diffusion of the wild boar in most of the mountain landscapes of Europe.

Corridors: Structure and functions

Corridors are functional structures in a landscape and their presence is fundamental to mitigate the effect of fragmentation or vice versa to increase the penetration of alien species. In other cases, corridors are structurally recognizable like hedgerows.

The corridor concept is not clear and is often used with different meanings. The corridor paradigm is extensively used in master planning and land remediation (Pirnat 2000). In organic farming, the utilization of corridors of natural vegetation has also been successfully tested (Nicholls et al. 2001). Corridors can be defined as narrow strips of habitat surrounded by habitat of other types. Across a corridor, plants and animals can move more easily, but a great variability in species behaviour exists along corridors. For some species of micro-mammals, corridors are difficult to verify (Mabry & Barrett 2002). In fact, there is little evidence that animals use structured corridors like hedgerows and fencerows, although differences have been observed according the sexes.

Gilbert et al. (1998) conducted fragmentation experiments on a moss matrix and discovered that the preservation of corridors between the isolated patches lowers the rate of loss of species richness and increases the patterns of gamma diversity, or the diversity of the entire fragmented system (Fig 14).

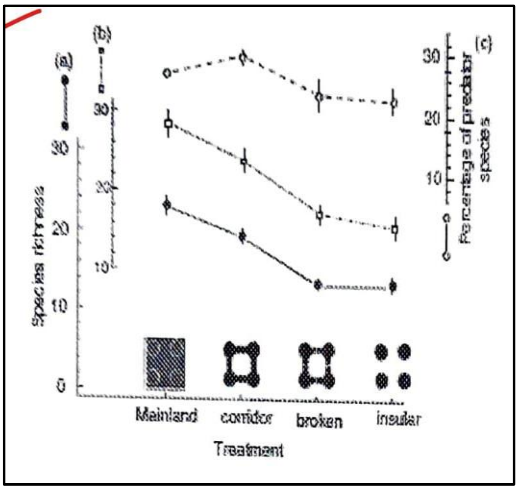


Fig 14: species richness of moss animal community according to the different experimental manipulation of moss cover (mainland, corridor, broken, insulator) (a) local species diversity; (b) gamma diversity, (c) richness of predators (Reff. Gilbert et al.)

For the maintenance of large home-range mammals like the cougar (*Felix concolor*), corridors appear to be essential corridors between the isolated patches lowers the rate of loss of species richness and increases the patterns of gamma diversity, or the diversity of the entire fragmented system (Fig 14). For the maintenance of large home-range mammals like the cougar (*Felix concolor*), corridors appear to be essential. This species needs a lot of corridors to support its way of life because it travels an average of 5.5 miles per night. Telemetry seems to be a very promising approach to understanding the mechanisms of landscape corridor selection by highly-vagile animals, then putting this information on a map and processing the data in a GIS, appears a very promising technique, although administrative and political restrictions in planning space for cougars and other large carnivores are the real limiting factor of the preserving action (Beier 1993).

Recently, using satellite telemetry techniques, Morreale et al. (1996) have tracked the oceanic movements of 8 female leatherback turtles (*Dermochelis coriacea*) after egg laying on the Costa Rica beaches (Fig 15).

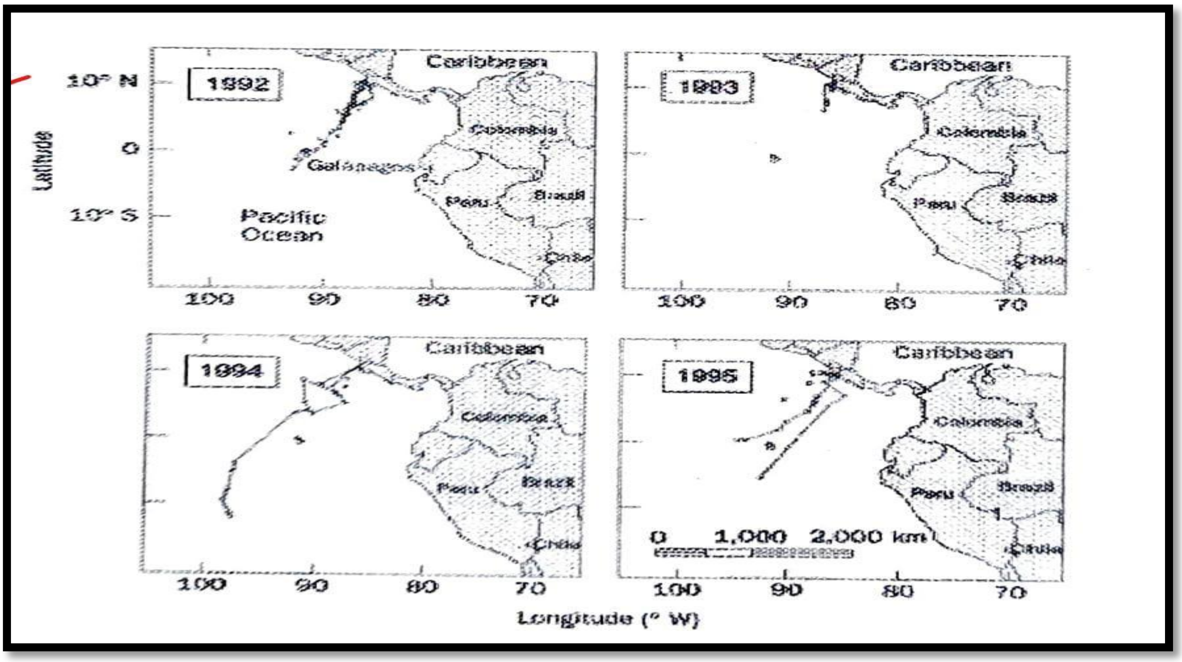


Fig 15. Migration routes of leatherback turtle monitored by satellite radio tracking from the Costa Rica breeding beaches to the deep ocean, after egg deposition (Reff. Murrreale et al. 1996).

Syllabus TOPIC 4 (D) Methods in landscape ecology, Spatial data processing, fractal geometry approach, urban ecology:

METRICS IN LANDSCAPE ECOLOGY:

The spatial elaboration of data is a central affair in landscape ecology and for this reason we will dedicate a large amount of space to the argument. Many techniques have been borrowed mainly from spatial statistics or geostatistics, for image analysis and fractal geometry. Euclidean and non-Euclidean geometry are often combined to analyze the complexity of spatial processes and patterns across temporal and spatial scales (Fig 17).

1. **Non-spatial metrices:** This section will describe some numerical indexes that have a very broad utilization in ecology and biology as well. Specifically, **Richness, Diversity and Evenness** are very useful to describe non spatial attributes of the landscape.

Richness: Richness It is the simplest attribute measurable in a collection. It is defined as the number (*S*) of different objects (organisms, patches, etc.) (*ni*) present in a collection.

$S = \sum n_i$

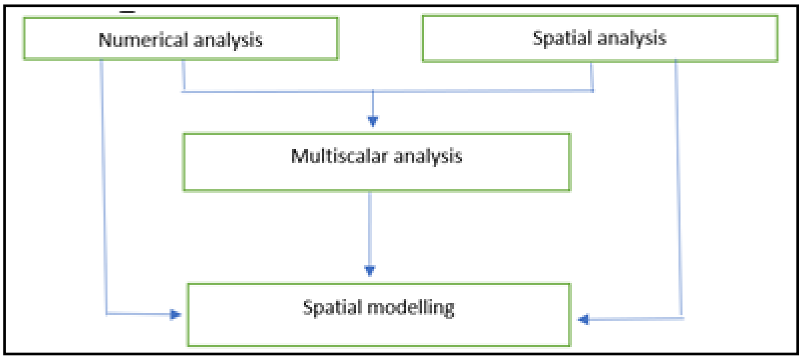


Fig 17. The principal approaches to landscape metrics (Reff. Farima 2000)

Diversity: This attribute describes the uncertainty by which we can encounter a new object, sampling a collection at random and it is the combination of richness and evenness. We present the Simpson and Shannon indices .The first index is particularly sensitive to the most abundant species and the second to the rarest.

Simpson Diversity (Simpson 1949)

$$d = \sum_{i=l}^{s} pi2$$

where S is the number of categories, pi is the relative abundance. pi=ni/N where ni is the abundance of category i and N is the total abundance.

where S is the number of categories, pi is the relative abundance. pi=ni/N where ni is the abundance of category i and N is the total abundance.

<u>Shannon Diversity:</u>

The variety and relative abundance of objects can be estimated by using the Shannon Index.

$$H' = \sum_{i=1}^{s} (Pi \ln Pi)$$

where pi is the relative importance of the category i .

<u>Evenness:</u>

This attribute describes the deviance between a maximum equipartition of the object into a collection (when every category has the same importance) and the distribution observed. Three indices are proposed:

Pielou Evenness (pielou 1975,1977)

$$E1 = \frac{H'}{\ln(S)}$$

Sheldon Evenness (sheldon 1969)

$$E2 = \frac{e^{H'}}{S}$$

Help Evenness (Help 1974)

$$E3 = \frac{e^{H'}}{S} - 1$$

Spatial metrics:

The Matrics describes in the section measure the spatial arrangement of the objects. Spatial configuration is recognised as important to assessing habitat suitability.

Relative Patchiness:

$$RP = 100 \sum \sum \frac{Eij\ Dij}{Nb}$$

n is the total number of patch types in a mosaic, Eij is the number of ages between patch types i and j, Dij is the dissimilarity value for patch types i and j , and Nb is the total number of ages of pixels (each pixel has four edges).

This index measures the contrast of neighbouring patch type in a landscape mosaic.

Entropy:

This index measures the disorder of pixels for each category.

$$ENT = -\sum \sum Pij \ln Pij$$

Pij is the probability of a grid point of land use, i is adjacent to a grid point of land use j. Pij represent the probability that land use type i adjacent to cells of type j. The Pij value is calculated by dividing the number of cells of type i that are adjacent to j by the total number of cells of type i present in the matrix. Pij=Nij/Ni, where Nij is the number of adjacencies between pixels of patch type i and j. Nj is the total number of cells of type i. Nij=Ni. Then Pij= 1.

THE FRACTAL GEOMETRY APPROACH:

Heterogeneity is a common pattern in the environment and is visible, especially at the landscape scale. Organisms, populations and communities have a spatial distribution that reflects the heterogeneous nature of the land. The unequal distribution of natural phenomena such as the geological nature of rocks, the rain distribution across a mountainous range or the distribution of tree cover in a watershed, all create complicated mosaics to which organisms react.

The word fractal was coined in 1975 by Mandelbrot to describe an irregular object in which the irregularity is present at all scales, scale-invariant. Mandelbrot (1986) proposed this definition "A fractal is by definition a set for which the Hausdorff Besicovitch dimension strictly exceeds the topological dimension." A fractal is a shape made of parts similar to the whole in some way. Fractals can be considered objects or patterns that have non-integer dimensions. When a fractal object has qualities of the patterns at coarse scale, which are repeated at finer and finer scale, this object shows self-similarity.(Fig 18).

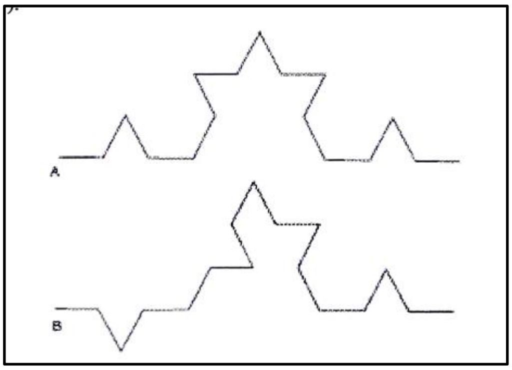


Fig 18. Example of regular(A) and a randomized (B) Koch snowflake

Two different types of fractals can be distinguished: regular fractals and random fractals. The first type is represented by scale invariant (self-similarity or self-affine) objects (Fig 19).

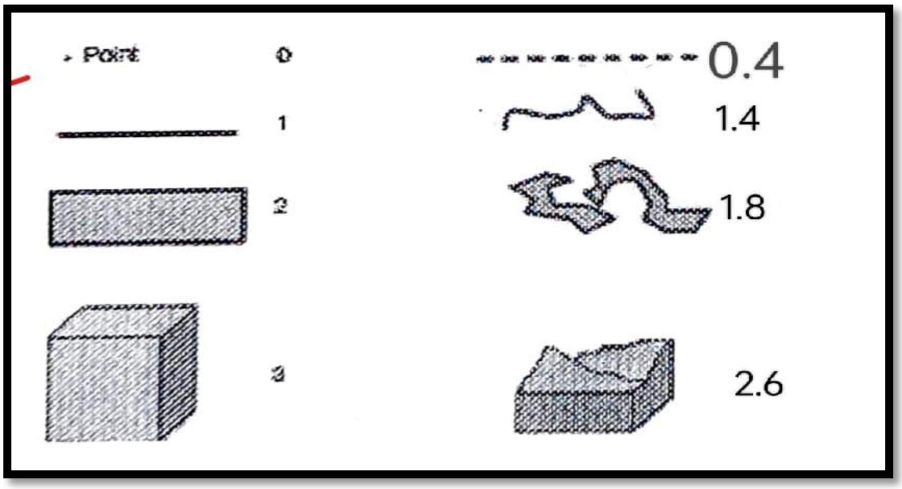


Fig 19. Comparison between Euclidean dimensions (left) and fractal dimensions (right).

Regular fractals have exact self-similarity. When an object is a rescaled copy of itself in all directions (isotropic), it has a self-similarity attribute. When the rescaling is anisotropic, the object presents a self-affinity.

The second category pertains to natural fractals (clouds, coastlines, organism abundance in the space, etc.). Generally, most of the natural fractals deviate from linear self-similarity and are called random fractals and display a statistical version of self-similarity. Related to self-similarity is the concept of scale-dependence. For instance, the coast is a fractal object for which the total length depends on the scale of resolution at which the measure is done. The complexity is measured with the fractal dimension D, which is the counterpart of the familiar Euclidean dimensions 0 (point), 1 (line and curves), 2 (surfaces), 3 (volumes) and it is never an integer. In a regular one-dimensional object, the mass increases in proportion to the length, say 2R. The mass in a two-dimensional disk with radius R increases in proportion to tR2, the area of a circle, in a three-dimensional object the mass increases of 4/3 tR3, which is the volume of a sphere. Adding dimensions, the mass increases according to the power of the number of dimensions. In fractal objects, the R is raised to some power Dm that is not an integer number. The fractal approach is intuitively easy to understand but it is necessary to develop and apply this theory to practice.

Probable questions:

1. What do you mean by disturbance?
2. Briefly discuss about the human disturbances.
3. Describe the fire disturbance in landscapes.
4. Describe the pathogen disturbance.
5. What is fragmentation?
6. What do you mean by structured fragmentation?
7. What do you mean by guild?
8. What do you mean by corridor? Mention different functions of corridor.
9. What is Simpson Diversity?

Suggested Readings:

1. Smith TM, Smith R L. 2006. Elements of Ecology. 6th Ed. Pearson Education
2. Chapman RL, Reiss MJ. 2000. Ecology - Principles & Application. Cambridge University Press.
3. Odum EP, Barret GW. 2017. Fundamentals of Ecology. 15th Indian reprint. Cengage learning India Pltd.
4. Ricklefs RE, Miller, GL. 2000. Ecology. 4th Ed. W. H. Freeman & Company.

UNIT XIX

Remote sensing in landscape ecology, Geographic Information System, Spatially explicit population models (SEPM)

Objective:

In this unit we will learn about remote sensing in landscape ecology, Geographic Information System, Spatially explicit population models (SEPM).

WHAT IS REMOTE SENSING?

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand, Kiefer, & Chipman, 2015).

REMOTE SENSING PLATFORMS AND SENSORS

Remote Sensing Platforms

Imaging in remote sensing can be carried out from both satellite and aircraft platforms. In many ways their sensors have similar characteristics although differences in their altitude and stability can lead to very different image properties.

There are essentially two broad classes of satellite program: those satellites that sit at **geostationary** altitudes above the earth's surface and which are generally associated with weather and climate studies, and those which orbit much closer to the earth's surface and that are generally used for earth surface and oceanographic observations. Usually, the low earth orbiting satellites are in a **sun-synchronous** orbit, in that their orbital plane precesses around the earth at the same rate that the sun appears to move across the earth's surface. In this manner the satellite acquires data at about the same local time on each orbit.

A more common image recording mechanism, used in the Landsat program, has been to carry a mechanical scanner that records at right angles to the direction of the satellite motion to produce raster-scans of data. The forward motion of the vehicle then allows an image strip to be built up from the raster-scans.

More recent technology utilises a "**push-broom**" mechanism in which a linear imaging array with sufficient detectors is carried on the satellite, normal to the satellite's motion, such that each pixel can be recorded individually. The forward motion of the satellite then allows subsequent pixels to be recorded along the satellite travel direction. As might be expected, the time over which the energy emanating from the earth's surface per pixel is larger with push broom scanning than for the mechanical scanners, generally allowing finer spatial resolutions to be achieved.

Aircraft scanners operate with essentially the same principles as those found on satellites. Both mechanical scanners and CCD arrays are commonly employed.

Image Data Sources in the Microwave Region

Side Looking Airborne Radar and Synthetic Aperture Radar

Remote sensing image data in the microwave range of wavelengths is generally gathered using the technique of side-looking radar. When used with aircraft platforms it is more commonly called SLAR (side looking airborne radar), a technique that requires some modification when used from spacecraft altitudes, as discussed in the following (Richards and Xiuping 2006).

Energy Sources and Radiation Principles

Visible light is only one of many forms of electromagnetic energy. Radio waves, ultraviolet rays, radiant heat, and X-rays are other familiar forms. All this energy is inherently similar and propagates in accordance with basic wave theory. The distance from one wave peak to the next is the wavelength λ, and the number of peaks passing a fixed point in space per unit time is the wave frequency υ.

From basic physics, waves obey the general equation (1.1)

$$\boldsymbol{c = \upsilon\lambda}$$

Because c is essentially a constant (3×10^8 m/sec), frequency ν and wavelength λ for any given wave are related inversely, and either term can be used to characterize a wave.

The "visible" portion of electromagnetic spectrum is an extremely small one, because the spectral sensitivity of the human eye extends only from about 0.4 μm to approximately 0.7 μm. The colour "blue" is ascribed to the approximate range of 0.4 to 0.5 μm, "green" to 0.5 to 0.6 μm, and "red" to 0.6 to 0.7μm. Ultraviolet (UV) energy adjoins the blue end of the visible portion of the spectrum. Beyond the red end of the visible region are three different categories of infrared (IR) waves: near IR (from 0.7 to 1.3 μm), mid IR (from 1.3 to 3 μm; also referred to as shortwave IR or SWIR), and thermal IR (beyond 3 to 14 μm, sometimes referred to as longwave IR). At much longer wavelengths (1 mm to 1 m) is the microwave portion of the spectrum.

Although many characteristics of electromagnetic radiation are most easily described by wave theory, another theory offers useful insights into how electromagnetic energy interacts with matter. This theory—**the particle theory**—suggests that electromagnetic radiation is composed of many discrete units called photons or quanta. The energy of a quantum is given as (Eq. 1.2)

$$\boldsymbol{Q = hv}$$

Where,

Q = energy of a quantum*;* joules (J)
h = Planck's constant, 6.626×10^{-34} J sec
v = Frequency

We can relate the wave and quantum models of electromagnetic radiation behaviour by solving Eq. 1.1 for $\boldsymbol{v}$ and substituting into Eq. 1.2 to obtain (Eq. 1.3)

$$\boldsymbol{Q = \frac{hc}{\lambda}}$$

Thus, we see that the energy of a quantum is inversely proportional to its wavelength. The longer the wavelength involved, the lower its energy content. This has important implications in remote sensing from the standpoint that naturally emitted long wavelength radiation, such as microwave emission from terrain features, is more difficult to sense than radiation of shorter wavelengths, such as emitted thermal IR energy. The low energy content of long wavelength radiation means that, in general, systems operating at long wavelengths must "view" large areas of the earth at any given time in order to obtain a detectable energy signal.

The sun is the most obvious source of electromagnetic radiation for remote sensing. However, all matter at temperatures above absolute zero (0 K, or - 273^0C) continuously emits electromagnetic radiation. Thus, terrestrial objects are also sources of radiation, although it is of considerably different magnitude and spectral composition than that of the sun. How much energy any object radiates is, among other things, a function of the surface temperature of the object. This property is expressed by the **Stefan–Boltzmann law**, which states that (1.4)

$$\boldsymbol{M = \sigma T^4}$$

Where,

M = total radiant exitance from the surface of a material*;* watts $(W)^{-2}$
σ = *Stefan–Boltzmann constant*, 5. 6697×10^{-8} W m^{-2} K^{-4}
T = absolute temperature (K) of the emitting material

It is important to note that the total energy emitted from an object varies as T^4 and therefore increases very rapidly with increases in temperature. Suffice it to say for now that the energy emitted from an object is primarily a function of its temperature, as given by Eq. 1.4.

The dominant wavelength, or wavelength at which a blackbody radiation curve reaches a maximum, is related to its temperature by **Wien's displacement law** (1.5)

$$\boldsymbol{\lambda m = \frac{A}{T}}$$

Where,

λm = Wavelength of maximum spectral radiant exitance, μm

A = 2898 μm K

T = temperature, K

Thus, for a blackbody, the wavelength at which the maximum spectral radiant exitance occurs varies inversely with the blackbody's absolute temperature. We observe this phenomenon when a metal body such as a piece of iron is heated. As the object becomes progressively hotter, it begins to glow and its colour changes successively to shorter wavelengths—from dull red to orange to yellow and eventually to white.

The earth's ambient temperature (i.e., the temperature of surface materials such as soil, water, and vegetation) is about 300 K (27°C). From Wien's displacement law, this means the maximum spectral radiant exitance from earth features occurs at a wavelength of about 9.7 μm. Because this radiation correlates with terrestrial heat, it is termed "thermal infrared" energy. This energy can neither be seen nor photographed, but it can be sensed with such thermal devices as radiometers and scanners. By comparison, the sun has a much higher energy peak that occurs at about 0.5 μm.

Energy Interactions in the Atmosphere

The atmosphere can have a profound effect on, among other things, the intensity and spectral composition of radiation available to any sensing system. These effects are caused principally through the mechanisms of atmospheric scattering and absorption.

Scattering

Atmospheric scattering is the unpredictable diffusion of radiation by particles in the atmosphere. Rayleigh scatter is common when radiation interacts with atmospheric molecules and other tiny particles that are much smaller in diameter than the wavelength of the interacting radiation. The effect of **Rayleigh scatter** is inversely proportional to the fourth power of wavelength. Hence, there is a much stronger tendency for short wavelengths to be scattered by this mechanism than long wavelengths.

Another type of scatter is **Mie scatter**, which exists when atmospheric particle diameters essentially equal the wavelengths of the energy being sensed. Water vapour and dust are major causes of Mie scatter. This type of scatter tends to influence longer wavelengths compared to Rayleigh scatter. Although Rayleigh scatter tends to dominate under most atmospheric conditions, Mie scatter is significant in slightly overcast ones.

A more bothersome phenomenon is **nonselective** scatter, which comes about when the diameters of the particles causing scatter are much larger than the wavelengths of the energy being sensed. Water droplets, for example, cause such scatter. They commonly have a diameter in the range 5 to 100 μm and scatter all visible and near- to mid-IR wavelengths about equally. Consequently, this scattering is "nonselective" with respect to wavelength. In the visible wavelengths, equal quantities of blue, green, and red light are scattered; hence fog and clouds appear white.

Absorption

In contrast to scatter, atmospheric absorption results in the effective loss of energy to atmospheric constituents. This normally involves absorption of energy at a given wavelength. The most efficient absorbers of solar radiation in this regard are water vapour, carbon dioxide, and ozone. Because these gases tend to absorb electromagnetic energy in specific wavelength bands, they strongly influence the design of any remote sensing system. The wavelength ranges in which the atmosphere is particularly transmissive of energy are referred to as atmospheric windows.

Energy Interactions with Earth Surface Features

When electromagnetic energy is incident on any given earth surface feature, three fundamental energy interactions with the feature are possible. Various fractions of the energy incident on the element are reflected, absorbed, and/or transmitted. Applying the principle of conservation of energy, we can state the interrelationship among these three energy interactions as (1.6)

$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda)$$

Where,

E_I = incident energy
E_R = reflected energy
E_A = absorbed energy
E_T = transmitted energy

with all energy components being a function of wavelength λ.

Spectral Response Patterns

Because spectral responses measured by remote sensors over various features often permit an assessment of the type and/or condition of the features, these responses have often been referred to as **spectral signatures**.

Although it is true that many earth surface features manifest very distinctive spectral reflectance and/or emittance characteristics, these characteristics result in spectral "**response patterns**" rather than in spectral "signatures." The reason for this is that the term signature tends to imply a pattern that is absolute and unique. This is not the case with the spectral patterns observed in the natural world. Spectral response patterns measured by remote sensors may be quantitative, but they are not absolute. They may be distinctive, but they are not necessarily unique.

Atmospheric Influences on Spectral Response Patterns

The atmosphere affects the "brightness," or radiance, recorded over any given point on the ground in two almost contradictory ways. First, it attenuates (reduces) the energy illuminating a ground object (and being reflected from the object). Second, the atmosphere acts as a reflector itself, adding scattered, extraneous path radiance to the signal detected by the sensor.

Geometric Influences on Spectral Response Patterns

The geometric manner in which an object reflects energy is an important consideration. This factor is primarily a function of the surface roughness of the object. **Specular reflectors** are flat surfaces that manifest mirror-like reflections, where the angle of reflection equals the angle of incidence. **Diffuse** (or **Lambertian**) reflectors are rough surfaces that reflect uniformly in all directions. Most earth surfaces are neither perfectly specular nor perfectly diffuse reflectors. Their characteristics are somewhat between the two extremes.

Diffuse reflections contain spectral information on the "colour" of the reflecting surface, whereas specular reflections generally do not. Hence, in remote sensing, we are most often interested in measuring the diffuse reflectance properties of terrain features.(Lillesand, Kiefer, & Chipman, 2015).

Resolution of Satellite Data: Types and Significance

Remote sensing images are characterised by their spectral, spatial, radiometric, and temporal resolutions.

Spatial resolution refers to the smallest features in the scene that can be separated (resolved) (Pushkar, Younan, & King, 2008).

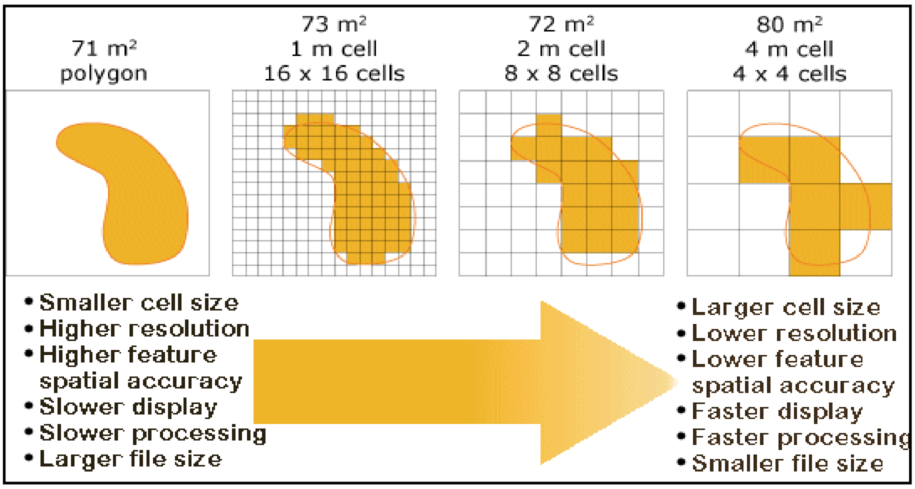


Figure 1: Spatial resolution (Image Cortsey ESRI)

Spectral resolution refers to the bandwidth and the sampling rate over which the sensor gathers information about the scene. High spectral resolution is characterised by a narrow bandwidth (Pushkar, Younan, & King, 2008).

The **radiometric resolution** refers to the dynamic range or the total number of discrete signals of particular strengths that the sensor can record. A larger dynamic range for a sensor results in more details being discernible in the image. The Landsat 7 sensor records 8-bit images; thus it can measure 256 unique grey values of the reflected energy while Ikonos-2 has an 11-bit radiometric resolution (2048 grey values). In other words, a higher radiometric resolution allows for simultaneous observation of high and low contrast objects in the scene.

The **temporal resolution** refers to the time elapsed between consecutive images of the same ground location taken by the sensor. Satellite-based sensors, based on their orbit, may dwell continuously on an area or revisit the same area every few days. The temporal characteristic is helpful in monitoring land use changes (Pushkar, Younan, & King, 2008).

Due to system tradeoffs related to data volume and signal-to-noise ratio (SNR) limitations, remote sensing images tend to have either a high spatial resolution and low spectral resolution or vice versa (Pushkar, Younan, & King, 2008).

Table 1: Landsat 8-9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)		
Bands	**Wavelength (micrometers)**	**Resolution (meters)**
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100

(USGS, 2022)

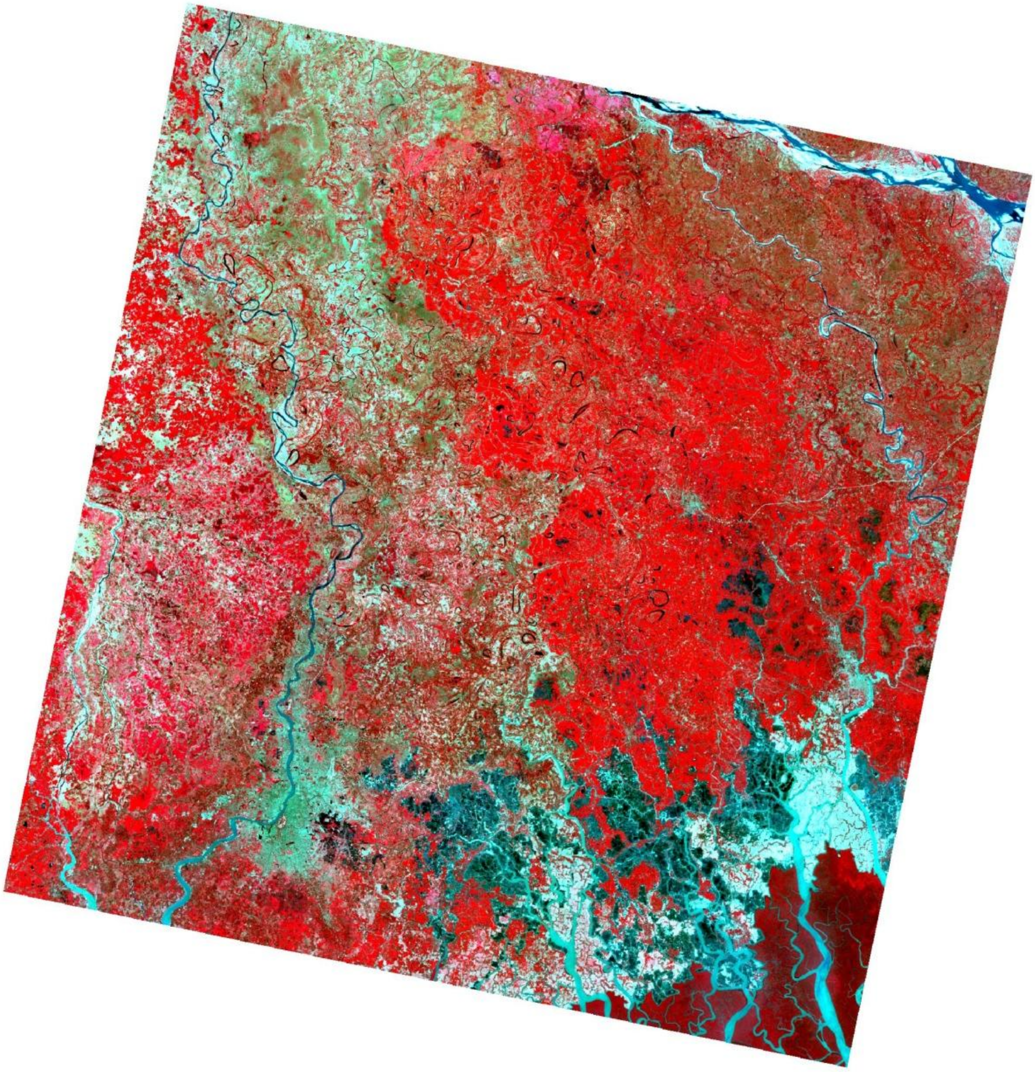


Figure 2: Standard False colour Composite prepared using Landsat 9; Path No 138/ Row No 44; Date of Acquisition 19-03-2022. The OLI-2 sensor collects image data in nine spectral bands over a 185 km swath. Three bands i.e. NIR, Red and Green bands have been assigned to Red, Green and Blue channels respectively. The Bhagirathi-Hooghly River can be seen flowing from north to south over Nadia district, West Bengal on left margin of the imagery. The skewed appearance of the imagery is due to the East to West rotation of the Earth while the satellite was scanning the area descending from North to South.

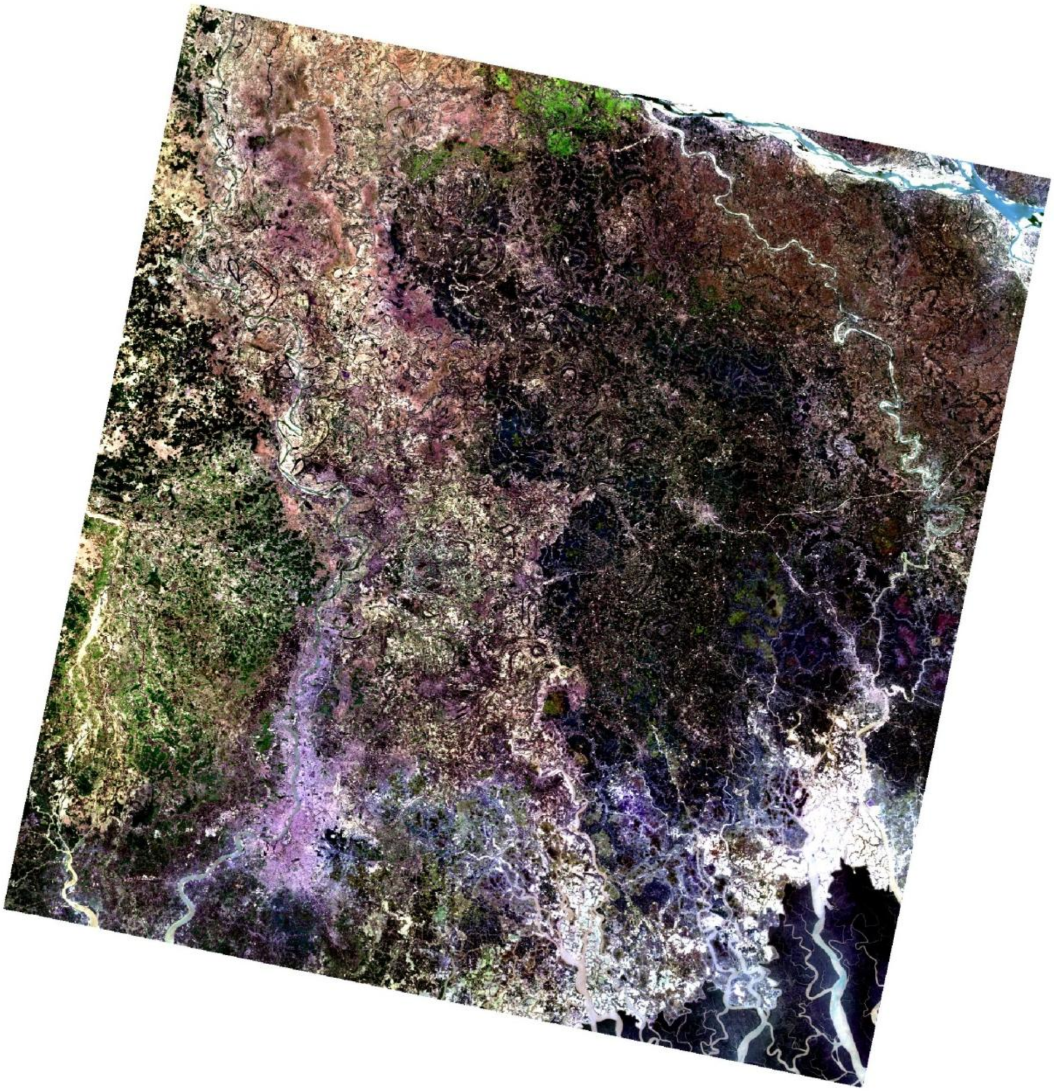


Figure 3: True Colour Composite prepared using Landsat 9; Path No 138/ Row No 44; Date of Acquisition 19-03-2022. Three bands i.e. Blue, Green and Red band have been assigned to Blue, Green and Red channels respectively. The image is less sharp than the above Standard False Colour Composite due to the effect of Rayleigh scattering.

WHAT IS GEOGRAPHIC INFORMATION SYSTEM (GIS)?

A GIS is a computer-based system that provides the following four sets of capabilities to handle geo- referenced data:

- Data Input
- Data management (storage and retrieval)
- Manipulation and analysis
- Output.

Sources of Data

- Geospatial data can be acquired from any number of sources such as printed maps, geospatial databases, or data acquired with the Global Positioning System (GPS).
- Geospatial data is generally grouped into two types: raster and vector.

Geographic Data Models

All GIS data attempts to define abstract real-world features in a data model, or format that can be understood by a computer.

- In the GIS world, there are two main data models used to represent features: the vector data model and the raster data model.
- The vector data model represents discrete objects on the surface of the earth—such as trees, rivers, or lakes—as point, line, and polygon features with well-defined boundaries.
- A raster data model represents the surface of the earth as a grid of equally sized cells. An individual cell represents a portion of the earth such as a square meter or a square mile.

Vector Data Model Vs Raster Data Model

- The vector data model represents geographic features with exactly defined boundaries, while the raster data model represents them as cells of the same value.
- Both the vector and raster data models are useful for representing geospatial data, but one may be more appropriate than the other when it comes to representing a particular type of geospatial data or answering different kinds of questions.
- In general, the vector data model is useful for representing features that have discrete boundaries, while the raster data model is most useful for representing continuous geospatial data—phenomena such as elevation, precipitation, and temperature—which do not have well-defined boundaries and which usually change gradually across a given area.

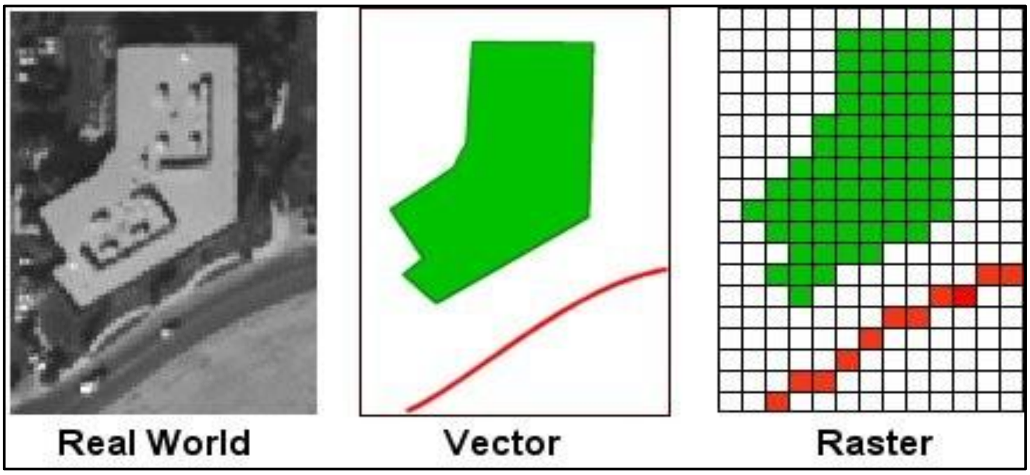


Figure 4: Representation of real world features through vector and raster data models

Raster Data

A raster is made up of a grid of square cells where all the cells are the same size. (Pixels is another term for cells. Short for "picture element," pixels usually refers to image cells.)

- Thus, an individual raster cell represents a portion of the earth such as a square meter or square mile.
- Each cell has a given value, depending on the type of dataset. In general, these cells are squares and are organized in rows and columns to form a rectangular dataset.
- The number of rows and columns in a raster does not have to be the same. For example, your raster may have 2000 rows and 1857 columns.
- The cell is the basic spatial unit of a raster. Each cell has a numeric value. Colors or shades are used to display the different cell values, yielding an image or a map of some kind.
- Raster datasets can represent non-geographic or geographic information. When rasters represent geographic information, they store the location and characteristics of each cell.
- Rasters may be categorized as one of two types: image rasters and thematic rasters. Image rasters are typically produced by an optical or electronic device such as a camera or scanner. Digital photographs or images are a type of raster dataset.
- Each cell represents a specific location on the earth.

- Thematic rasters represent geographic features or phenomena with either discrete or continuous data. Digital elevation models (DEM) are a common type of thematic raster dataset.

- Each of the cells in a DEM raster represents the elevation of that point on the earth's surface.

- Together, imagery and DEMs can provide a wealth of information about the topography of a region.

Raster Values

Raster datasets represent data using either integers (whole numbers) or floating points (numbers with decimals).

- Integer rasters are used to represent discrete data, such as landuse, and floating point rasters are used to represent continuous data, such as like elevation or slope.

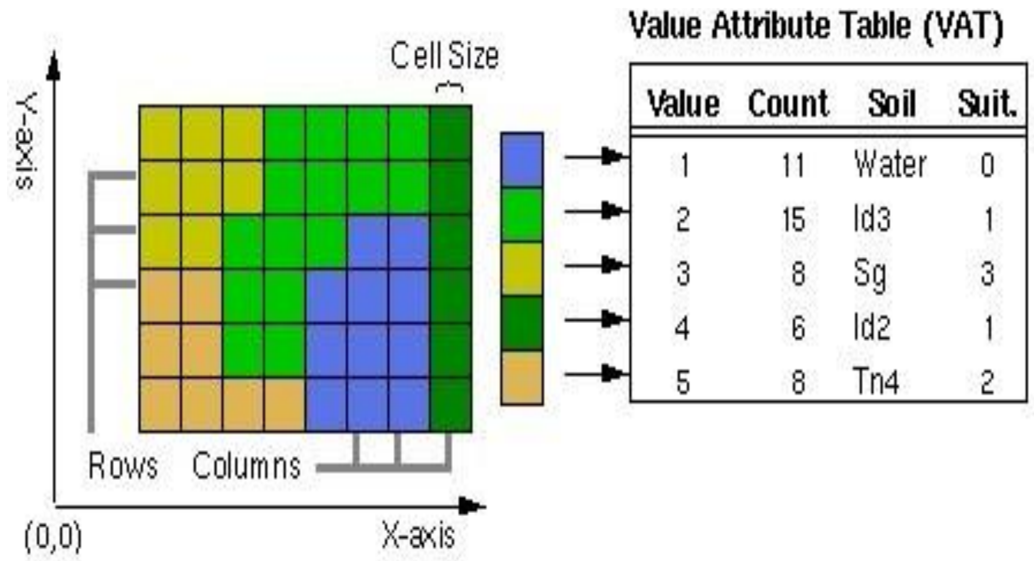


Figure 5: A VAT has one record for each unique value in the grid.

- A discrete raster dataset contains cells whose values are integers, often code numbers for a particular category. Cells can have the same value in a discrete raster dataset. Integer raster datasets have a value attribute table (VAT) that stores the cell values and their associated attributes.

- Unlike discrete raster datasets, continuous raster datasets (floating point raster datasets) do not have an attribute table because each cell in a continuous raster dataset can have a different floating point value. Cells in this type of raster dataset do not fall neatly into discrete categories.

Raster bands

A raster dataset can be either simple (one layer) or composite (a collection of multiple layers). These raster layers are referred to as bands.

- Thematic rasters and panchromatic images are examples of simple raster datasets. Many types of imagery such as multispectral satellite imagery, are composite rasters.
- When there are multiple bands, every cell location has more than one value associated with it.
- A raster dataset can have multiple bands. For example, each band in a multispectral image represents different parts of the electromagnetic spectrum. Every cell in the image has a data value for each band.
- Cell values in single-band rasters are usually displayed using a gray-scale or a colour map.
- In gray-scale, shades range between black and white. In a colour map, cell values are arbitrarily matched to particular colours.

Spatial Reference for Rasters

A dataset's spatial reference describes where features are located in the real world. The spatial reference includes a coordinate system for x-, y-, and z-values as well as resolution and tolerance values for x-, y-, z-, and m- values.

Coordinate systems

All geospatial raster datasets are in some coordinate space. This coordinate space may be a real-world coordinate system such as latitude and longitude, or one based on the raster's cells.

- In the raster, cells are referenced by their row and column position. The rows and columns are numbered from the top left corner of the raster, starting with zero. The cell in the top left corner has row and column coordinates of 0,0. This cell is known as the raster's cell origin.

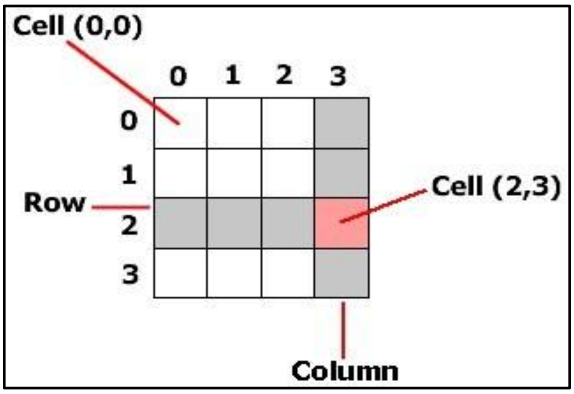


Figure 6: every cell in a raster can be uniquely identified by its row and column position. For example, the red cell is at row 2 and column 3.

A raster that represents geographic information uses a Cartesian coordinate system to reference cells to a location on the earth.

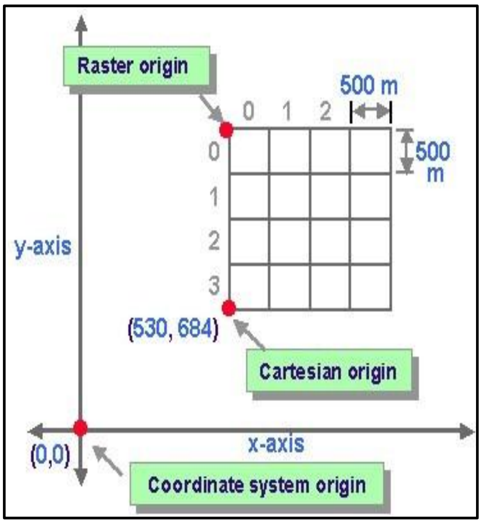


Figure 7: A raster that represents geographic information has a second origin for the Cartesian coordinate system, the bottom left corner.

Spatial Resolution or Cell Size

Spatial resolution refers to the area of the real world represented by one cell in the raster. A high-resolution dataset will have cells that represent relatively small areas in the real world, thereby providing more detail. A low-resolution dataset will have cells that represent a large area and provide a "summary" of the area in question.

Vector data

- The vector format is an excellent way to store information about discrete geographical locations, features, or regions.

- While rasters often represent data that is continuous or thematic (e.g., images, temperature, precipitation), vector data is used more often to represent discrete objects such as trees, streets, or buildings.

- In geodatabases, a vector object is known as a feature, and related features are organized into groups called feature classes. Unlike rasters, where information is stored within each cell of the raster, the attributes of vector data are associated with features.

- ArcMap displays what are called layers. A layer references the information contained in a feature class or raster, rather than actually storing it.

Vector data model

- The vector data model is based on the assumption that the earth's surface is composed of discrete objects such as trees, rivers, and lakes.

- Objects are represented as point, line, and polygon features with well-defined boundaries.

- Feature boundaries are defined by x,y coordinate pairs, which reference a location in the real world.

- Points are defined by a single x,y coordinate pair.

- Lines are defined by two or more x,y coordinate pairs.

- Polygons are defined by lines that close to form the polygon boundaries.

- In the vector data model, every feature is assigned a unique numerical identifier, which is stored with the feature record in an attribute table.

Feature attributes

- On a GIS map, there is more to a feature than its location and shape. There is all the information associated with that feature. For a road, this might include its name, speed limit, and whether it is one-way or two-way. For a city, this might include its population, demographic characteristics, number of schools, and average monthly temperatures.

- Information associated with a feature in a GIS is called an attribute. For example, population can be an attribute of a city, country, continent, and other features. Feature attributes are stored in an attribute table.

- In an attribute table, each feature is a record (row) and each attribute is a field (column). The attributes for all the features in a layer are stored in the same attribute table.
- Each feature in a feature class—essentially, a group of related features—may have any given number of attributes. Each attribute value can be categorized as one of four levels of measurement: nominal (such as ID numbers or names), ordinal (rankings), interval (on a scale with no "natural" zero), or ratio (on a scale with a "natural" zero).

Vector formats

- As with the raster data formats, there are a number of file formats for storing vector data.
- Shapefiles are universal exchange files (unlike the geodatabase). The term "shapefile" is somewhat misleading, as a shapefile actually comprises a group of separate files.
- ArcMap and ArcCatalog make these separate files invisible to the end user by displaying them as a single file with a SHP extension.
- Another format that has become popular is the Keyhole Markup Language (KML) file. KML files have either a KML file extension or a KMZ file extension (for compressed and zipped KML files).
- Each KML file is composed of a collection of graphic elements, images, and settings. KML is used to do the following:
- Symbolize and display GIS data as elements within Google Earth and Google Maps using symbols, color, images, and balloon-style information pop-ups.
- Provide access to attribute information about geographic features—for example, by presenting attribute information when you click a feature's symbol.

There are a number of other vector formats that are occasionally used. Two of the more common formats are the

- AutoCAD Drawing Exchange Format (.DXF) and
- The United States Geological Survey (USGS) Digital Line Graph (.DLG) format.

Attribute tables

- A feature on a GIS map is linked to its record in the attribute table by a unique numerical identifier (ID). Every feature in a layer has an identifier.
- When you select a record in the table, the linked feature on the map is automatically selected as well.

Using attribute queries

- To find features that meet specific attribute criteria, you create a query expression.
- A query expression is a logical statement consisting of three parts: a field name (attribute), an operator, and an attribute value.
- Query expressions can be linked together to include multiple criteria. Expressions that contain multiple criteria are called compound expressions.

Accessing more attributes

- Not all feature attributes are stored in a layer attribute table. In many GIS databases, user- defined attributes (as opposed to software-generated attributes) are stored in separate, nonspatial tables.
- When you want to find features based on their attributes, sometimes you will need to associate a nonspatial table to the layer attribute table before you can perform the query.
- You can associate a nonspatial table to a layer attribute table if they share a common field; that is, a field that stores the same data.
- The names of the common field do not have to be the same, but the field types (e.g., text, short integer) must be.

Raster model	Vector model
• Simple data structure • Easy and efficient overlaying • Compatible with Remote Sensing imagery • High spatial variability is efficiently represented Simple for programming by user • Same grid cell definition for various attributes • Inefficient use of computer storage Errors in perimeter and shape Difficult to perform network analysis Inefficient projection transformations • Loss of information when using large pixel sizes Less accurate and less appealing map output	• Complex data structure Difficult to perform overlaying • Not compatible with RS imagery • Inefficient representation of high spatial variability • Compact data structure Efficient encoding of topology • Easy to perform network analysis • Highly accurate map output

Spatial Analysis: Raster and Vector Based

VECTOR BASED ANALYSIS

- **Map Overlay**
  - Union, Intersect
  - Point in Polygon, Line in Polygon, Polygon on Polygon
- **Map manipulation**
  - Dissolve, Clip, Append, Eliminate, Update, Erase, Split
- **Proximity Analysis**
  - Buffer, Multiple Ring Buffer, Point Distance
- **Pattern Analysis**
  - Nearest Neighbour Analysis, Spatial Autocorrelation
- **Network Analysis**
  - Shortest route

RASTER BASED ANALYSIS

- **Functions**
  - Local, Focal , Zonal , Global
- **Map Algebra**
  - Operators: Boolean, Relational and Arithmetic
  - Functions: Mathematical, Logarithmic, Arithmetic, Trigonometric, Power
- **Terrain Analysis**
  - Derivatives: Contour, Slope, Aspect, Hillshade, Viewshed
- **Hydrology Analysis**
  - Flow Directions, Flow Accumulation, Stream Order, Watershed etc.
- **Reclassification**

RELATIONSHIP BETWEEN REMOTE SENSING AND LANDSCAPE ECOLOGY:

That the relationship between remote sensing and landscape ecology is significant is due in large part to the strong spatial component within landscape ecology. The large number and range of landscape ecological studies and applications that use remote sensing in one way or another confirms their connectivity. In part, this relationship is characterised by a constant factor, namely that remote sensing provides often the spatial component in landscape ecology; aerial photography and its interpretation was the starting point for Carl Troll to coin the term landscape ecology. It is also an evolving relationship, as new possibilities are explored based upon technical developments, including those represented by newly launched satellite sensors and novel image interpretation methods.

Spatial coverage, synoptic overview

A key feature of the relationship between remote sensing and landscape ecology is the spatial extent of information collection that remote sensing makes possible. This is most notably associated with satellite images, with many examples of individual image scenes that cover areas extending over tens and hundreds of kilometres. Much satellite imaging operates globally, irrespective of borders, each with its own history in surveying and mapping, the relevance of satellite images for harmonisation of regional landscape work is also significant. Remote sensing is, compared to other survey techniques, unique in its possibilities for providing census data, i.e. complete large area coverage that can complement sample data. ‘Completeness’ is one of the underlying principles of a classification system, i.e. that it is exhaustively inclusive of the objects within its domain. By their blanket coverage image data provide a strong physical basis for compliance to this principle. Moreover, the synoptic overview represents for landscape ecology more than merely the possibility to capture within one data source information for a large area. More fundamentally it represents the possibility to see patterns that are only discernible when a larger part of the landscape is in view. Repeat coverage Compared to other major sources of spatially extensive information for landscape ecology, such as field data collection or map products, remote sensing provides significant possibilities for frequent data capture. Spatial-temporal analysis of landscapes often can only be done through the use of remotely sensed data, and archive images represent a major opportunity to re-visit the landscape of the past. Aerial photographs, which are stored in many national archives from at least the early 1940s, represent image contributions in the temporal domain with a long history, while imaging from Space plays a significant role from the 1970s. Furthermore, within the temporal domain provided by many satellite sensors, with repeat periods of between 15 min and a few weeks, it is also possible to undertake ecological work concerning the monthly, seasonal and yearly dynamics of landscapes.

Abstraction-free landscape information

To function as science, landscape ecology requires landscape information. Two important data collection methods are field survey and use of topographic maps. Notwithstanding their significance, both these methods have limitations. Field data collection is time consuming, often difficult to undertake and expensive. Potentially more problematic, existing map data may be readily available but represent a highly abstracted and filtered representation of the landscape. For example, a topographic map is a cartographic product and is the result of applying a specific set of rules of what features within the landscape should be mapped and how they are represented. This means in general a strong simplification of reality. Working with remote sensing images is therefore seen as a means that has the potential for capturing landscape information through use of a data source that is effectively free of human abstractive processes. The visual impact of remote sensing images as pictures of ‘how the landscape actually is’ operates highly effectively. This is particularly so with photographic image data (such as aerial photography) in which the general level of detail seen is close to that which might be noted in a live viewing. Moreover, in many types of field surveys the synoptic information provided by remote sensing images can help in preparations for efficient fieldwork. **Standardisation**

As with any technique for making physical measurements it is important for their use that the individual data are comparable. Moreover, this is a fundamental requirement for a technique such as remote sensing that is largely based around visualisation. Thus, most remotely sensed data sets are characterised by high levels of internal data standardisation. Image data standardisation is also normally based upon fundamental physical principles, enabling the calculation or estimation of many land surface properties such as moisture content and biomass. Data standardisation is particularly the case for satellite remote sensing, with control possible over parameters, such as illumination and viewing angles, that can otherwise result in aberrant data values. Standardisation is also present with respect to the principle way by which remote sensing data are provided, i.e. as rasterised data in widely usable computer file types.

Remote sensing and landscape ecology: new trends

Maybe there has never been a time since the beginnings of remote sensing from Space in the 1960s when there has not been some new remotely sensed image data set providing new sources and types of information and new opportunities for applications. Indeed, the pace of technical development of imaging sensors and platforms is as rapid now as ever. Recent technical developments in remote sensing for land surface information extraction comprise a broad range. However, whilst developments such as multi-angle viewing, hyperspectral sensing and radar have considerable potential relevance for landscape ecology the developments. These developments are seen as having more general and greater immediate impact on the interface between landscape ecology and remote sensing than other developments, in which in many cases there is still major work to be undertaken in understanding the principles involved (Groom, Mucher, Ihse, & Wrbka, 2006).

SPATIALLY EXPLICIT POPULATION MODELS (SEPM)

Introduction

Population simulation models have evolved in complexity and sophistication in the past decade, increasing the potential utility of these models for a wide variety of applications. Simulation models have become important in the study of population dynamics in heterogeneous landscapes. In particular, population models that incorporate the habitat complexity of real-world landscapes can be used to examine possible population response to regional or global change. These models, therefore, show promise as tools for conservation biologists and land managers.

Definition and Current Structure of SEPMs

Spatially explicit models have a structure that specifies the location of each object of interest (organism, population, habitat patch) within a heterogeneous landscape, and therefore the spatial relationships between habitat patches and other features of the landscape (e.g., landscape boundaries, corridors, other patches) can be defined. Since the spatial layout of the landscape is explicitly incorporated, the models can be used to indicate how populations or communities might be affected by changes in landscape structure, including changes in landscape composition (the relative or absolute amount of habitat types or features in a landscape) or landscape physiognomy (the exact placement of habitat patches and other features within the landscape).

Structure

Two important components of the structure of any landscape model are the model's grain and extent. The grain of a landscape is the smallest patch size, which defines the lower limit of resolution of the landscape map. Each individual patch is usually assumed to be homogeneous in its local habitat characteristics. The extent of a landscape is defined as the largest scale being covered by the study and is set by the size of the landscape map. Most SEPMs currently under development for relatively mobile vertebrate species examine individuals and populations that inhabit microscale to mesoscale areas. Other spatially explicit models are being developed to cover even larger areas, especially for the study of global climate change.

Types of landscapes

With the use of more sophisticated technologies, it is possible to capture the heterogeneity of real-world landscapes. This is particularly true of landscape maps created with geographic information systems (GIS). Habitat maps for a given species can be created by overlaying a grid of cells onto a GIS map of a given region and then assigning all of the characteristics of the underlying habitat polygons to each cell of the grid. Landscapes also can be made more realistic by introducing temporal as well as spatial variation of the landscape.

Individual-based vs. population models based

Many of the SEPMs under development are individual- based. In these models, the location of each individual across the landscape is monitored, and individuals acquire fitness characteristics associated with the cell type they occupy. The status of each individual is followed through an entire simulation. SEPMs can be population-based, where each cell contains a population. This may be the most appropriate modeling strategy for abundant organisms such as rodents or insects in models where it may be difficult to follow each individual in a large population.

Movement and dispersal rules

Perhaps the most important difference between SEPMs and other landscape models is that SEPMs can incorporate movement of organisms between specific patches across the landscape and quantify how this movement may affect population dynamics. Rules of movement can allow for both the temporary movement between patches for individuals searching for food, predator refuges, or mates; and the more permanent movements of dispersing individuals. Movement rules can specify boundary effects, dispersal mortality, and use of corridors or other landscape features.

Limitations

SEPMs are not a panacea for population ecologists. At their present level of development, the models have limitations. Currently, the best SEPMs cannot predict, with any high degree of quantitative accuracy, the eventual number of organisms that might be found in a particular landscape. Like any model, many simplifications must be made to make these models tractable and comprehensible. Furthermore, there are unknowns such as many aspects of dispersal behavior. These simplifications and unknowns make it impossible to predict the population size of species X at time Y in landscape Z.

Future Goals

We believe that modeling spatially explicit landscapes can improve our ability to do ecological research in two major ways. First, better development of SEPMs will improve our ability to model realistic landscapes, allowing us to better understand population and community responses to environmental change. Second, SEPMs will allow us to ask different questions and increase the impact that landscape approaches are already having on ecological research. Currently, most SEPMs are capable of making qualitative predictions as to which environmental or life history variables are likely to have the biggest effect on population dynamics What is not generally possible at present are quantitative predictions of actual population responses to specific environmental changes. Therefore, a major focus of research needs to be on increasing the predictive ability of models (DUNNING JR, et al., 1995).

Probable questions:

1. What is remote sensing?
2. Describe briefly the energy interactions in the atmosphere.
3. What do you mean by scattering?
4. What do you mean by absorption?
5. Discuss energy interactions with earth surface.
6. Write down full form of SEPM.
7. Describe the current structure of SEMP.

Suggested Readings:

1. Dunning Jr, J. B., Stewart, D. J., Danielson, B. J., Noon, B. R., Root, T. L., Lamberson, R. H., et al. (1995). Spatially Explicit Population Models: Current Forms And Future Uses. *Ecological Applications* , 3-11.

2. Groom, G., Mucher, C., Ihse, M., & Wrbka, T. (2006). Remote sensing in landscape ecology: experiences and perspectives in a European context. *Landscape Ecology* , 391-408.

3. Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2015). *Remote Sensing and Image Interpretation.* USA: Wiley.

4. Pushkar, P., Younan, N. H., & King, R. L. (2008). Concept of Image Fusion in Remote Sensing Applications. In T. Stathaki, *Image Fushion.* Academic Press.

5. Richards, J. A., & Xiuping, J. (2006). *Remote Sensing Digital Image Analysis: An Introduction.* Germany: Springer.

6. USGS. (2022). *Landsat 9 data Users Handbook.* South Dakota: USGS.

Disclaimer: This self-learning material is compiled from different books, journals and web-sources.

UNIT XX

Organic evolution: concept and evidences (comparative anatomy, embryology, biogeography, palaeontology, genetics, biochemistry and physiology)

Objective:

In this unit we will discuss about concept of organic evolution and evidences (comparative anatomy, embryology, biogeography, palaeontology, genetics, biochemistry and physiology).

Introduction:

Organic Evolution is a process by which organism changes itself to adapt best with the environment. It, in fact, signifies that animals after their origin have descended from their ancestors with modifications, resulting in the variety of today.

The complex animals and plants of today are the result of a series of slow and steady changes of simpler-forms of the by-gone days through generations which have taken place during millions of years. The principle of evolution is supported by numerous facts or evidences, which are apparently indirect and can be summed up under the following heads.

1. Evidences from Comparative Anatomy or Morphology:

(a) Basic relationship:

A basic relationship exists between all animals from lowly organized to most highly evolved, in the structure and composition of protoplasm and cells. The cells, however, exhibit difference in shape and size in response to functions but their fundamental constitution remains unchanged.

Throughout the animal kingdom the protoplasm contains very nearly the same elements almost in the same proportions of proteins, carbohydrates, fats, water and other substances.

(b) Homologous organs:

Homologous organs are those which are developmentally alike and may or may not perform similar functions. The limbs, brains, hearts, etc. of different vertebrates are homologous organs.

Thus the skeletal elements in the wings of pterodactyls (extinct flying reptiles) birds and bats are homologous in that all are modifications for flight of the common pattern of fore limb in land vertebrates.

The wings of insects are analogous to those of vertebrates, although used for flight, they are derived not from limbs, but presumably as extension of the body wall (Fig.21).

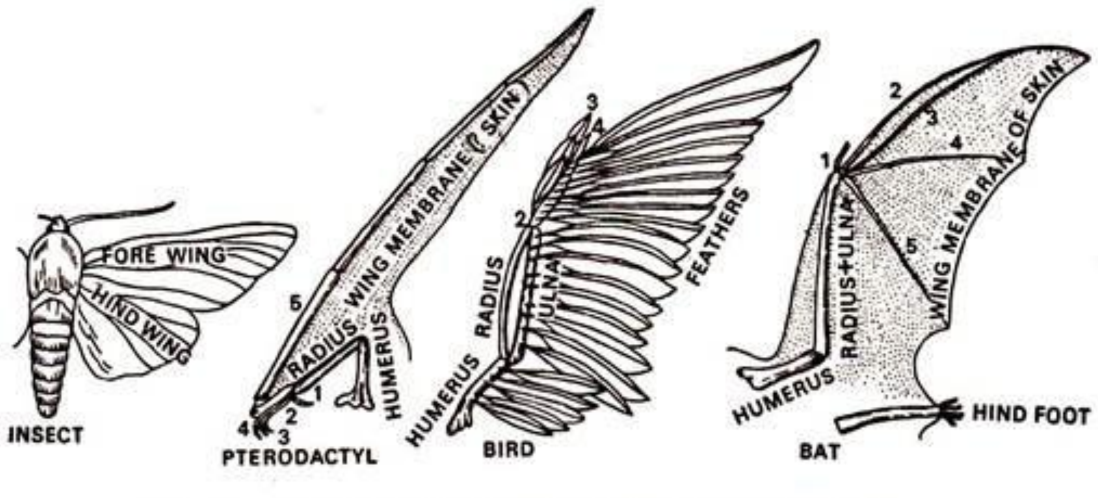


Fig. 21 . Analogy between wings of insects and vertebrates

Homologous structures are present in different groups of animals. The fore and hind limbs of different vertebrates are pentadactyl (Fig.22).

A comparison of the fore limbs of salamander, crocodile, bird, bat, whale, mole and man shows that the limbs are homologous in being composed of comparable bones, which in each group of animals are adapted for special uses by differences in the length, shape and bulk of various bones.

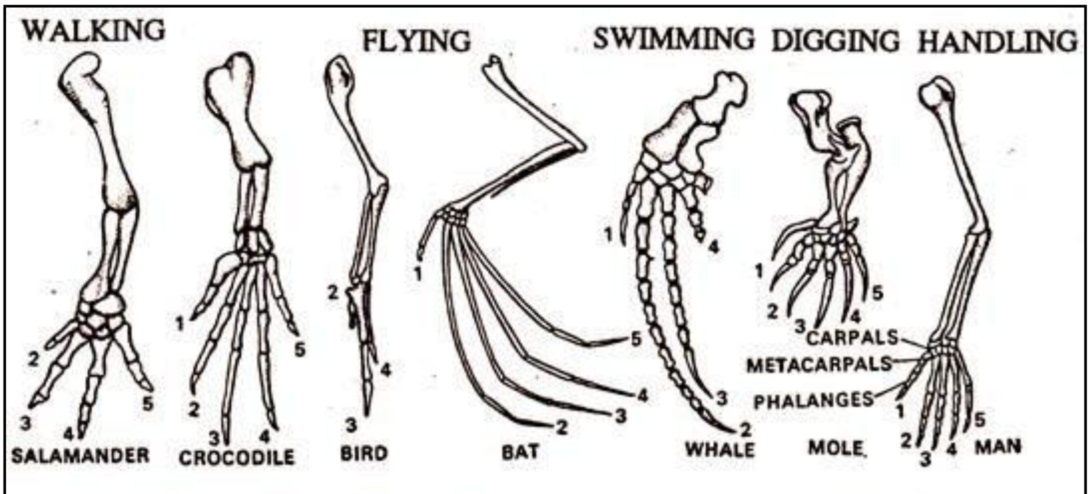


Fig. 22 . Homology and adaptation in bones of left fore limbs in land vertebrates

Fore limbs of salamander and crocodile are used for walking, those of birds and bats help in flying, and that of whale for swimming, mole for digging and man for handling objects.

In all vertebrates the heart is ventrally placed and circulation takes place through a closed system of vessels, arteries and veins. A gradual evolution towards perfection is found in different classes of vertebrates. It is two-chambered in fishes, three-chambered in amphibians and reptiles and four-chambered in birds and mammals, completely separating the arterial and venous blood.

The presence of identical organs in different groups of vertebrates can only be explained by accepting that all of them are descendants of a common ancestor, from whom they inherited these structures, but as they are variously modified, the minute structural differences are due to various life conditions to which they have been subsequently adapted.

(c) Connecting links:

It is proved that the mammals, like the birds, have evolved from reptiles. But, these two groups of animals are widely separated by striking differences, which, however, may be thought to be bridged over, if some intermediate animals with some common characters are found.

Monotremes are animals found in Australia, in which most important characters of reptiles and mammals are combined and serve as a link between these two groups. They possess hairs and mammary glands like the mammals but lay eggs like reptiles and again suckle the young after hatching. It is presumed that monotremes are in the making of mammals from reptiles.

The fossil bird *Archaeopteryx* (Fig. 25) connects the reptiles with the birds. This bird had teeth and long tail like reptiles and wings with feathers similar to birds.

(d) Vestigeal organs:

Organs which were once well developed and functional but have been rendered functionless due to change of environment and are in the way of degeneration, are known as vestigeal organs.

The handful of bones in the pelvic girdle of whales, the small amount of flesh (rudimentary nictitating membrane) at the inner corners of our eyes, the caecum, and the coccyx in man, the pair of vestigeal wings in the flightless New Zealand Kiwi are the examples of vestigeal organs. Their presence indicates that the possessors have originated from a group of animal in which these structures were functional.

2. Evidences from Embryology:

The law of embryo-genic development states (a) General characters appear in development prior to special characters, (b) From the general, the less general, and ultimately the special characters develop, (c) During development an animal gradually drifts progressively from other animals, (d) Young stages of an animal resemble the embryonic or young stages of lower animals but are unlike the adult of those animals.

A common basic plan of development with similar embryonic stages exists in different classes of vertebretes (Fig. 23). All of them in their foetal stages possess visceral clefts and a visceral skeleton, though not used for respiration in true land vertebrates, viz. the reptiles, birds and mammals.

Certain larval stages are common to some groups of invertebrates also. The trochophore larva is found both in Annelida and Mollusca; the nauplius larva is common to most of the orders of the class Crustacea.

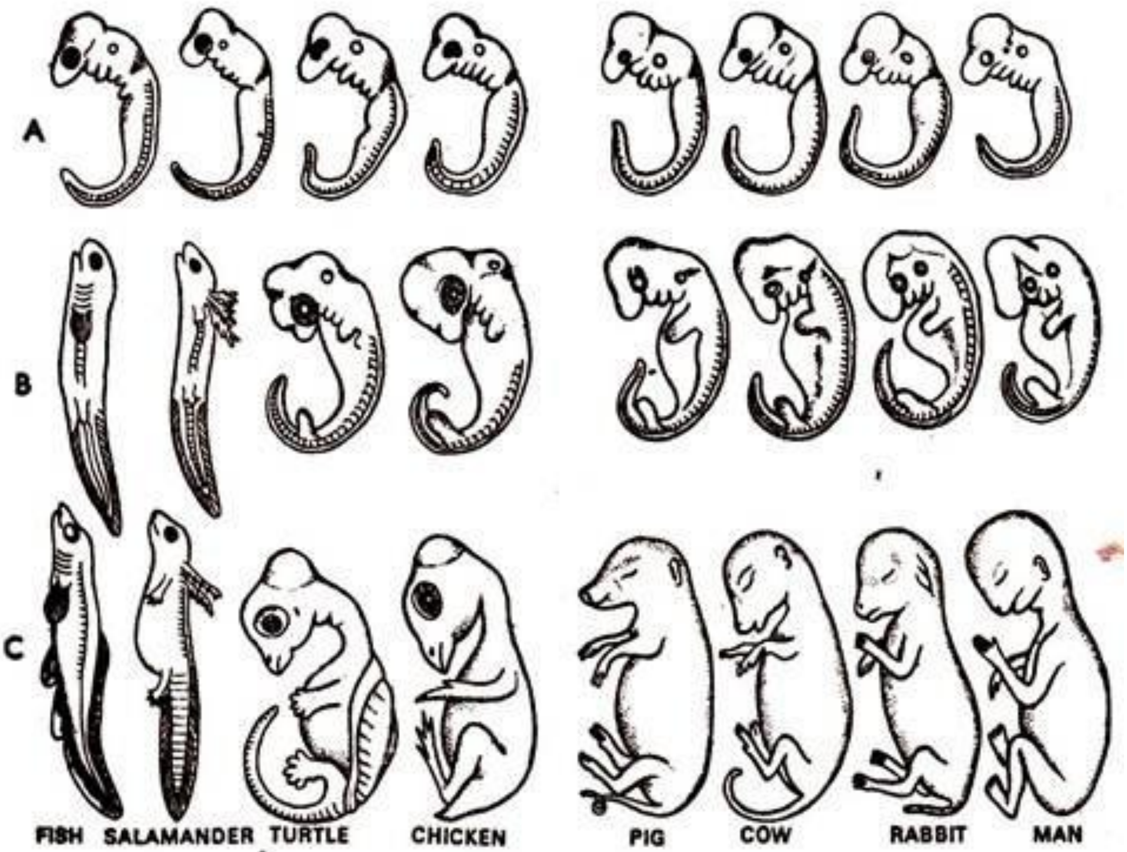


Fig. 23 . Series of vertebrate embryos in three successive and comparative stages of development

A. All are much alike in the earliest stage

B. Differentiation has set in but the four mammals (right) are similar

C. Late stage : each with its distinctive features

All vertebrate embryos develop a series of aortic arches (usually six) running from the ventral aorta to the dorsal aorta similar to Branchiostoma (amphioxus). In course of development the number of aortic arches are reduced to five in sharks, four in teleosts, three in amphibia and reptiles and two in birds and mammals.

From the development of some organisms it is revealed that in some cases the embryos do not resemble the parents but resemble the adults of lowly evolved animals. The tadpole larval stage of frogs and toads is exactly like a fish. It is believed that the larval stages of an animal repeat the structures of the ancestor from which it has evolved.

This is also known as 'Ontogeny recapitulates Phytogeny', or the development of an individual repeats the evolution of the race in a condensed form. Now-a-days this principle is used in a very limited sense, because the pattern of development is liable to alternations to some degree, due to the influence of the environment and also the amount of yolk present in the egg.

3. Evidences from Palaeontology:

Palaeontology is the science of fossils. Fossils are the remains of animals and plants of the by-gone days and are of six types. Fossils are present in different layers of earth's crusts.

Lower the layer, older is the age of the organisms and the reverse. The age of a geologic strata may be accurately determined by either lead method or radio-carbon method. The oldest era with animal fossils for certain is the Proterozoic (2,000 million years).

Beginning with invertebrates (505 million years), reptiles (255 million years) appeared in the Paleozoic era (505-230 million years). Birds and small mammals evolved in the Mesozoic era (205-135 million years) or the age of reptiles, when dinosaurs reached peak and became extinct. The last or Cenozoic era (75-0 million years) has been marked by the rise to dominance of mammals and man, and is still in progress.

Fossil records definitely indicate trend of evolution through different era.

- **Mollusca:**

The trends of evolution of fossil ammonites (Cephalopoda) reveal coiling at the initial stage, and uncoiling of the shell at a later period. Structures between successive chambers were simpler in the older stocks and more complex in those of later periods.

The first chambers formed by some of the later ammonites were simple, like those of their ancestors. Then, surprisingly, some of the last ammonites had simpler sutures again and their shells were coiled in the young but straight in the adult stages. Finally, the entire line of ammonites ended in the Cretaceous period (Fig. 24).

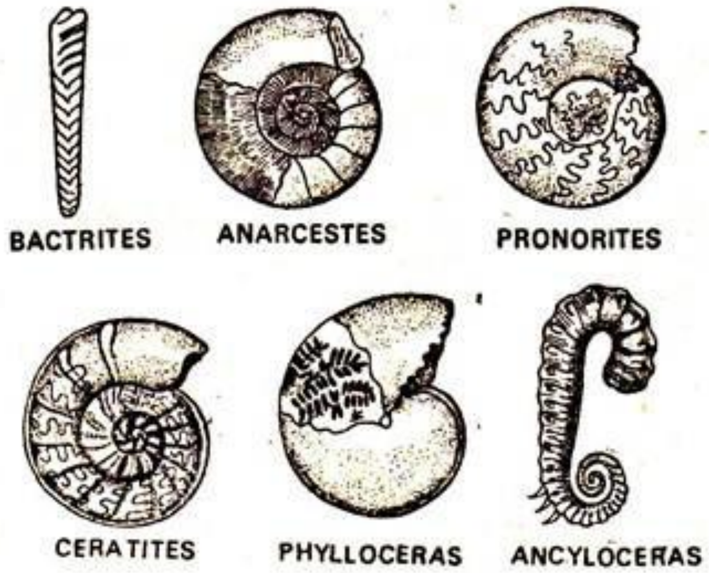


Fig. 24 . Stages in evolution of the fossil ammonites. Coiling and later uncoiling of the shell and changes in the forms of the sutures

- ***Archaeopteryx:***

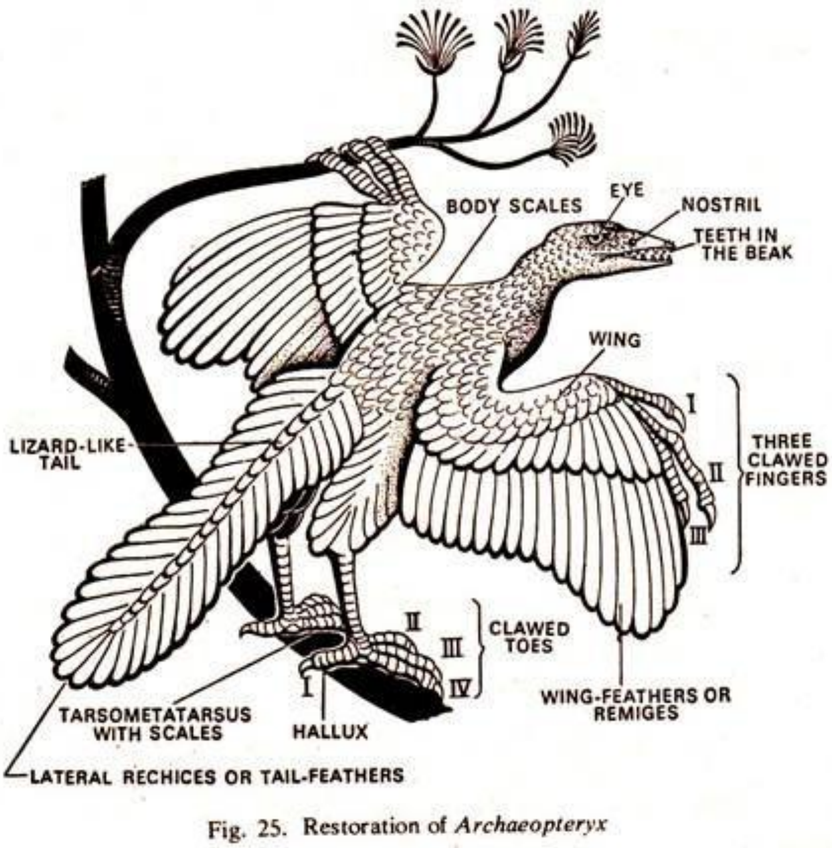


Fig. 25. Restoration of *Archaeopteryx*

An extinct bird, possessed feather like most birds but unlike them had homodont reptilian teeth and a less developed forelimb (Fig.25). These explain that Archaeopteryx represents a stage in the evolution of birds from reptilian ancestors. Birds appeared later than mammals but very soon they became specialized and static.

The mammals were in the process of continuous change, the primitive egg laying forms gave rise to more specialised ones, first the marsupials, then the placentals. From the study of the fossils, complete evolutionary histories of horse, camel and elephant have been revealed and we can read the story step by step.

Evolution of the Horse:

The history of the horse covers a period of 50 million years beginning in the Eocene period. The known ancestor of the present day horse *Equus* was Hyracotherium (including Eohippus of others).

The browsing, less than one foot high ancestral, horse changed through Mesohippus (Oligcene, 39 million years), Miohippus, Parahippus, Merychippus (Miocene, 28 million years), and Pliohippus (Pliocene, 12 million years) to Equus (Pleistocene to recent 1-0 million years).

The evolution of Equus from Eohippus is a history of the enlargement of the body both in length and girth, loss of digits in both pairs of limbs, transformation of low-crowned cheek teeth to high-crowned and highly specialised for grinding coarse, siliceous grasses, associated with many other changes (Fig.26).

Fossil records also suggest that a number of animals have become extinct for various reasons. This is very conspicuous in reptiles. Dinosaurs (large lizard-like), pterodactyls (flying reptiles) and ichthyosaurs (fish-like reptiles) are all extinct.

Fossilization and types of fossils:

(a) Preservation of hard parts:

The endoskeleton of vertebrates and exoskeleton of invertebrates are preserved unaltered. From such fossils it is possible to get some idea about the shape, size and posture of animals.

(b) Foot prints:

The foot prints left on soft mud are preserved by subsequent hardening of the mud into rock. These provide clues for body structure, locomotory organs and mode of locomotion of animals.

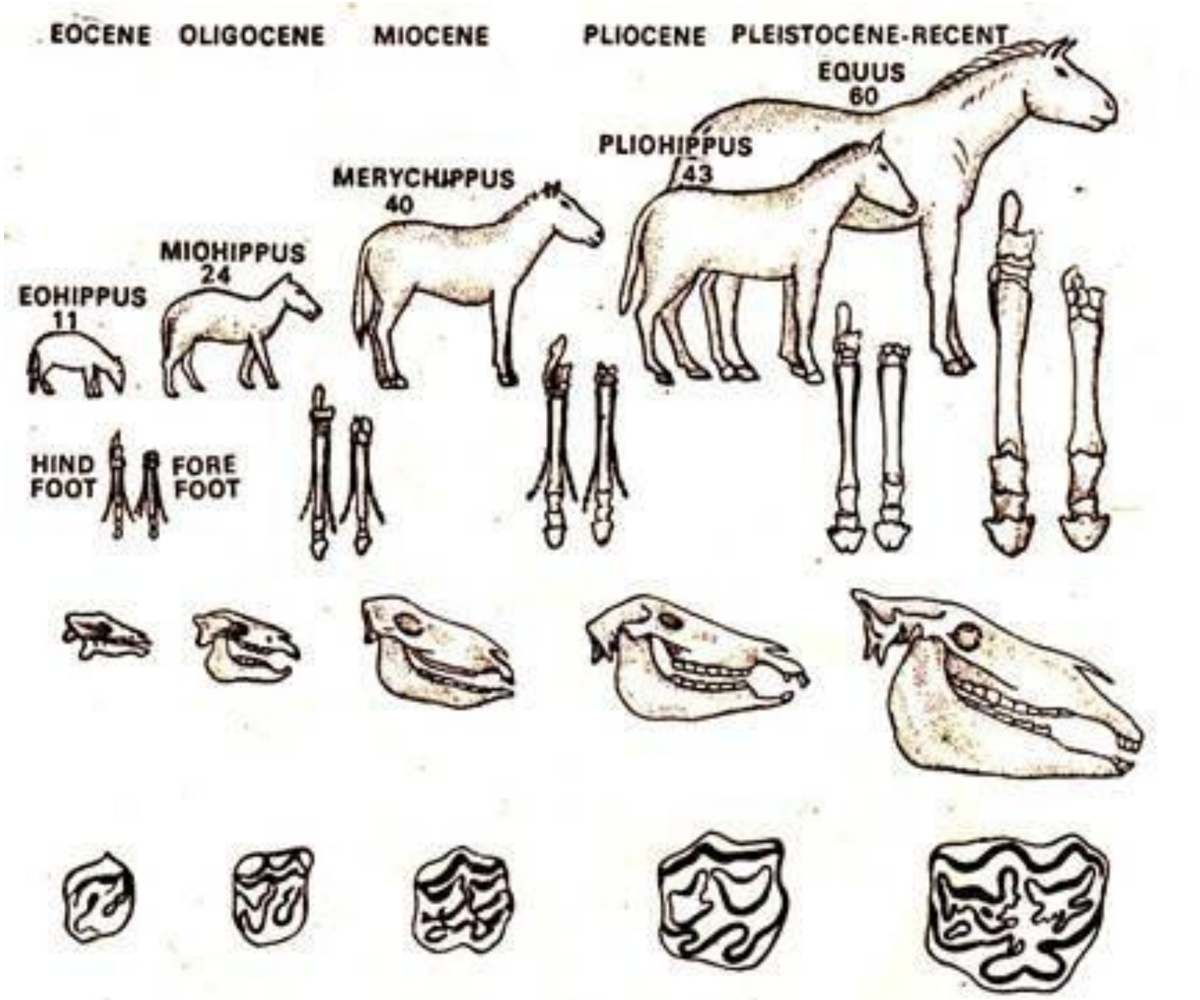


Fig. 26. Evolution of Equus

Top row. Progressive change in size and conformation

Second row. Bones of hind and fore feet showing reduction in number of lateral toes (solid black)

Third row. Skulls showing changes in size and outline and closing of postorbital process

Bottom row. Grinding surface of second upper molar showing increasing complexity of the enamal pattern (black)

(c) Petrified fossils:

The organic substances of the body are replaced by inorganic substances particle by particle in minute detail and an exact duplicate is left. The replacement is so perfect that muscle fibres with cross striations are recognized.

For the formation of petrified fossil the organism or part of it must be embedded and buried in some soft medium. This may happen either at the bottom of a body of water or on land by accumulation of wind-blown sand, soil or volcanic ash.

The dead, body is subsequently covered with layers of mud. The organic substances of the body are slowly replaced by minerals from the surroundings and gradually turn to hard rock.

Sedimentary rock containing fossils may be carried by the rivers to sea, where it sinks to the bottom, and deposited in subsequent layers. Entire body or parts of organisms are often included in these layers.

(d) Mould and Casts:

The natural moulds of organisms are formed by hardening of materials surrounding buried bodies, which later disintegrate and are removed by seepage of the ground; leaving a hollow cavity. It presents the exact external features of the organism buried. The soft animals like Jelly fish, worms etc. are preserved in this way.

(e) Amber preservation:

Sometimes delicate animals, viz. crustaceans, insects, spider etc. are preserved in oil shales, asphalt, amber etc.

(f) Ice preservation:

The carcasses of many animals are preserved as such within ice at sub-zero temperature. Wooly mammoth, rhinoceros of past have been recovered from Siberian ice.

4. Evidences from Geographical Distribution:

The distribution of animals and plants on the earth's surface is not uniform. Every country has its peculiar flora and fauna. Elephants are found in Africa and Asia, Tigers in parts of Asia, Rhinoceros in Africa and India, Kangaroos in Australia and South America, Lions in India-and Africa, and so on. Particular species of organism evolves at a particular place and with the increase in number they migrate in all available directions.

Climatic conditions in no two places are exactly alike and the organisms exhibit modifications. Due to different barriers, populations are separated or isolated. Mutations appear in the population and isolation prevents the spread of the changes to other populations. This is continued and gradually by accumulation of more mutations one or more new species are formed from a population.

5. Evidences from Genetics:

A number of mutations or sudden inheritable variations appear in organisms. They can occur in all parts of the body and in all conceivable directions. On accumulation, mutations give rise to new species. Some important mutations include Ancon Sheep, Double Toed Cats, Hornless Cattle, Red Sunflower, Large-sized Banana, etc.

Rabbits were introduced in the island of Porto Santo in the fifteenth century. They underwent mutations. Today Porto Santo rabbits are smaller than the original stock, have different colour pattern and are more nocturnal. They do not breed with the parent stock.

Light coloured moth *Bison betularia* underwent a mutation to produce a dark from *Biston carbonaria*. The latter is more suitable for industrial areas and has survived while the white parent form is now restricted to small unpolluted pockets.

6. Evidences from Comparative Physiology and Biochemistry:

Comparative physiology and comparative biochemistry lend much support to the idea of evolution. In addition to cells, the basic structures of chromosomes, the physical basis of heredity, in diverse organisms are similar.

Throughout the living world, the chromosomes consist of basic proteins in combination with nucleic acid. Histone and protamine, the simplest types of proteins predominate, but globulin and some incompletely identified proteins, probably contributing to the diversity of hereditary materials are also present.

(a) Enzymes, hormones and hematin crystals:

Identical or closely similar enzymes and hormones are common to large groups of animals. Digestive enzyme, viz. trypsin (proteolytic enzyme) is common in animals Protozoa to Mammalia. Amylase (starch-splitting enzyme) has been recorded from sponges to man.

The thyroid hormone is found in all vertebrates and it is interchangeable, i.e. beef thyroid can be used to meet thyroid deficiency in man. Metamorphosis of a tadpole larva continues if it is fed with mammalian thyroid after the removal of its own thyroid gland.

Various classes of vertebrates can be distinguished on the basis of haematin crystals alone prepared from the haemoglobin. The crystals differ from species to species in structural details and they parallel the present classification. Crystals from different species of a genus share many common characteristics, and crystals from different classes also have some common structures.

(b) Comparative serology:

Impressive physiological evidences have been drawn from the study of comparative serology. If a small amount of blood serum of an animal is injected into another animal, viz. guinea pig or rabbit or other test animals the foreign blood acts as an antigen and antibodies are produced in the blood of the test animal.

If a second injection is given to the test animal with the serum from the first animal, the antibodies precipitate and destroy the antigen. The test animal is then said to be immunized to the particular kind of blood. The precipitation occurs in the blood stream but it can be carried in test tubes by adding a few drops of antigenic serum to the antiserum obtained from immunized animal, when a precipitate will be formed.

Antigen-antibody reactions are highly specific, still the reactions take place in related species, but in ever-decreasing degrees as the relationship grows more distant. A rabbit may be immunized with the blood from Necturus, the common salamander.

If a few drops of antigenic serum from Necturus, Amphiuma, Siren and Cryptobranchus are added to different test tubes containing antiserum from the immunized rabbit, the heaviest precipitation will occur in the first tube, the second and third will give about equal precipitates but less than the first, and the fourth will give only a slight precipitate.

These suggest Necturus, Amphiuma and Siren are closely related while Cryptobranchus is a much more primitive salamander.

This method is being applied in the problems of plant taxonomy also. Here, plant proteins are antigen and rabbit is the test animal. It has been possible to ascertain the relationship between plants with antibody containing serum from immunised rabbit.

Probable questions:

1. What do you mean by Organic evolution?
2. Who is the father of organic evolution?
3. Discuss the Comparative Anatomy or Morphological evidence of organic evolution?
4. What do you mean by homologous organ?
5. What do you mean by connecting link?
6. Discuss the embryological evidence of organic evolution?
7. Discuss the palaeontological evidence of organic evolution?
8. Discuss the role of *Archaeopteryx* in organic evolution.
9. Discuss elaborately the evolution of the horse.
10. What do you mean by vestigial organ? Give example.
11. What do you mean by fossilization? Name different types of fossils.
12. Define petrified fossils.
13. What do you mean by amber fossil?
14. What is mould and casts?
15. Discuss the evidence from Comparative Physiology and Biochemistry of organic evolution?

Suggested Readings:

1. Dobzhansky T, Ayala FJ, Stebbins JL, Valentine JW. 1977. Evolution. Surajeet Pub., N.Delhi
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4. Ridley M. 1996. Evolution. 2nd Edn. Blackwell Science.

Disclaimer:

The study materials of this book have been collected from books, various e- books, journals and other e-sources.