Unit - 13

Insect Ecology-I

Structure of the Unit

13.1 Objectives

By the end of the chapter, the student would acquaint himself with the different aspects of interactions of insects with different abiotic factors of ecosystem like temperature, relative humidity, light, air and water currents, influence of biotic Factors like intraspecific Interactions – Competition, Sex relations, Reproduction, Parental care, Cooperation, aggregation, colonial and social life and interspecific interactions like competition, Commensalism, Symbiosis, Parasitism – host interactions, Predators-prey interaction. The concept of population dynamics, different modes for sampling, population Growth, Causes of Population Fluctuations, Host plant insect interactions, Biochemical adaptation against environmental stress – Hibernation, Aestivation, Dormancy, Quiescence, Diapause, Polymorphism and Swarming in different insects

13.2 Introduction

Ecology is a science, emerged as a distinct discipline only at the turn of the 20th Century and became prominent in the second half of the 20th Century. **Ernst Heinrich Philipp August Haeckel**, was an eminent German biologist, naturalist, philosopher, physician, professor and artist who described this term first time. The **insect ecology** is the scientific study of how insects, individually or as a community, interact with the surrounding environment or ecosystem. In a broader perspective the ecology is a study of the structure and function of nature as proposed by some earlier ecologists. Ecology the study of organism in relation to their environment has developed in recent years from the descriptive attempt to describe nature, the natural history of yesterday.

Ecosystem, the basic functional unit of ecology, is composed of abiotic (non-living) components of the environment and biotic (living) community both interacting with each other. An insect being the member of the biotic community interacts with other living members of the community as well as with the non-living (abiotic) components of the environment. The outcome of these interactions is the population dynamics, the positive or negative growth of the population. Hence the life system, existence, abundance, and evolution of insects can be understood by the study of interactions between insects and abiotic factors and insects and biotic factors and population dynamics.

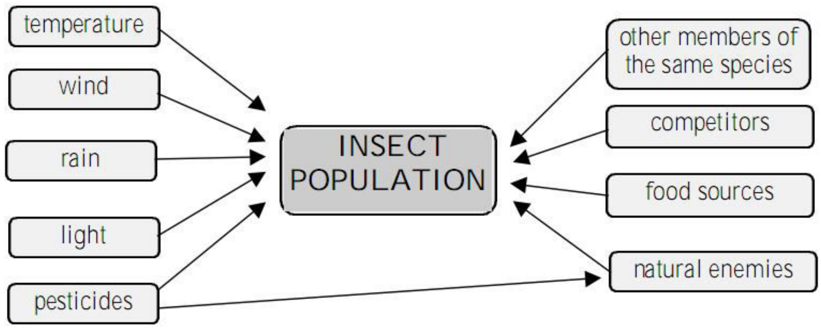
Insects are the dominant group of organisms on earth, in terms of both taxonomic diversity and ecological function. Insects play significant roles in the ecology of the world due to their vast diversity of form, function and life-style; their considerable biomass; and their interaction with plant life, other organisms and the environment. Since they are the major contributor to biodiversity in the majority of habitats, except in the sea, they accordingly play a variety of extremely important ecological roles in the many functions of an eco-system. Taking the case of nutrient recycling; insects contribute to this vital function by degrading or consuming leaf litter, wood, carrion and dung and by dispersal of fungi.

Insects form an important part of the food chain, especially for entomophagous vertebrates such as many mammals, birds, amphibians and reptiles. Insects play an important role in maintaining community structure and composition; in the case of animals by transmission of diseases, predation and parasitism, and in the case of plants, through phytophagy and by plant propagation through pollination and seed dispersal. From an anthropocentric point of view, insects compete with humans; they consume as much as 10% of the food produced by man and infect one in six humans with a pathogen.

13.3 The environment of an insect population consists

•**Physical factors (abiotic factors)** such as temperature, wind, humidity, light and pesticides

•**Biological factors (biotic factors)** such as other members of the same insect species; food sources; natural enemies (including predators, parasitoids and diseases) and competitors (other organisms that use the same space or food sources).



13.3 Abiotic factors

The Abiotic components of the insect environment, mainly include temperature, moisture, light, air and water currents and others. These have been found to be significant in their influence on insect.

The abiotic factors like temperature, moisture and light are not uniform throughout an ecosystem. They are variable not only in different parts of ecosystem but also in different parts of a plant. And therefore, the effect of an environmental component, like temperature, may be described accurately only in terms of the temperature in a specific part of an ecosystem. This has led to develop the concept of microenvironment which implies the variation in environmental component within the ecosystem.

The main abiotic factors influencing insects are temperature, moisture, light and air and water currents.

Temperature

Insect maintain body temperatures within certain boundaries. The temperature in the environment is variable. Thus the insects have to bear the effects of constant temperature which may at times be below or above the optimum temperature range as well as the varying temperature.

Insects have traditionally been considered as **poikilotherms** which means animals in which body temperature is variable and dependent on ambient temperature as opposed to being **homeothermic** animals which maintain a stable internal body temperature regardless of external influences. However, the term thermoregulation, is currently used to describe the ability of insects and other animals to maintain a stable temperature either above or below ambient temperature, at least in a portion of their bodies by physiological or behavioural means. While many insects are ectotherms, the animals in which their heat source is primarily from the environment, others are endotherms, the animals which can produce heat internally by biochemical processes. These endothermic insects are better described as regional heterotherms because they are not uniformly endothermic. When heat is being produced, different temperatures are maintained in different parts of their bodies, for example, moths generate heat in their thorax prior to flight but the abdomen remains relatively cool.

The various factors of Insects influenced by temperature are as follows-

Distribution of Insects

- The distribution of insects is affected by abiotic factor temperature particularly in low temperature zones. The distribution limit of insects in the northern extreme in temperate zones is determined by the low temperature extremes. Below the extreme distribution limits there is a zone which is densely populated during summer but during winter the insects usually die. The insects are abundant in high temperature zones because of variations in the temperature. As insect in north has less number of generations in a year as compared to the insect of southern zone. The rate of dispersal of insects is dependent on the temperature. Insects are more active in tropical zone than in temperate zone.

Insect Body Temperature

- Sun radiations and metabolic rate are major sources of heat gain. It is due to solar radiation that the temperature of the insect body becomes different from the ambient temperature. The different factors like size, color, and shape of the insects and orientation with respect to sun, influence the effect of solar radiation on the insect body temperature. A larger surface area having insect is more affected than the smaller insect. As per the scientific principle the colour and energy are interdependent therefore the insects colours of lighter colours absorb less radiations, than the dark ones. The insect with more surface exposed to radiation absorbs more heat.

- Heat loss in an insect is caused by various processes like evaporation, convection, conduction and long-wave radiation. In case of solar radiation the metabolic heat is the only source of heat during movement of insects. The break-down of complex organic molecules results in metabolic heat stored in the high energy bonds of ATP. In the absence of solar radiation the major loss of heat from the body takes place by evaporation. The rate of evaporation is dependent partly on the size of the insect. A smaller insect loses more water than the larger insect as the smaller insect has a larger ratio of surface area to volume.
- The movement of air also increases the heat loss as a steep gradient is maintained on insect and its surroundings. Hairs and scales present on the body of insects prevent the heat loss. In the event of a fall in surrounding temperature the insect maintains its body temperature by active body movement and muscles contractions. For example in Sphingididae family moths the body is kept warm by continuous wings movements. The activity of insects is directly proportional to the body temperature. When the body temperature falls, the metabolism slows down and its activity retards whereas on rise in the body temperature, the insects become more active until at a certain temperature it becomes inactive. A further rise in temperature causes death.

Vital Temperature

- The highest temperature limit at which the insect just lives and dies beyond it, is known as a vital temperature maximum while the lowest temperature at which the insect can live but may not exhibit any activity is called the vital temperature minimum. Usually 46^{D} C is the vital temperature maximum in insects but it varies in different species under different conditions. For example stored grain pest *Rhizopertha dominica* dies at a temperature of 62.8 ^{D} C exposed for 5 minutes. Hibernating insects can survive at a very low temperature of -50^{D} C.

Insects Mortality

- Insects survives themselves within the particular optimum range of temperature. An exposure to the temperatures above or below the extremes of optimum range is always fatal to insects. The optimum range of temperature depends on the specific species. It also depends on the physiological state of the individual insect. Some insects can tolerate the lower temperature during fall and winter than in the spring or summer. Insects of tropics tolerate less of cold than those of temperate areas.

Survival Range

- The insects remain active between the upper and lower tolerable limits of temperature but become inactive at both the extremes. Most of the insects survives in temperature between 0 and 50^{D} C, with few exceptions that can survive even beyond the extremes of this range. Certain larvae of dipteran insects can survives even at the temperatures of 55^{D} C or higher. Insects living at high altitude can complete their entire life cycle at temperatures of even below 0^{D} C.

Acclimation

- Acclimation is the process in which an individual organism adjusts to a gradual change in its environment such as a change in temperature, humidity, photoperiod, or pH, allowing it to maintain performance across a range of environmental conditions.

Low Temperature Acclimation

- The insects have been found adapted in the arctic by showing cold hardiness. Certain insects like *Aedes aegypti* can survive at low temperatures for a longer period and even show acclimation to cold but die due to freezing of the body fluids. Some insects can withstand super cooling thus can prevent freezing. The presence of some cryoprotective compounds in haemolymph such as sorbitol, glycerol and erythritol which depresses the haemolymph freezing point are helpful in freezing tolerant insects. During their inactive stage, the glycerol appears in the tissue and disappears soon after this state is over.

High Temperature Acclimation

- High temperature acclimation is useful to insects living under natural circumstances of daily high temperatures.It has also been observed in certain insects like *Calliphora* and *Phormia*.

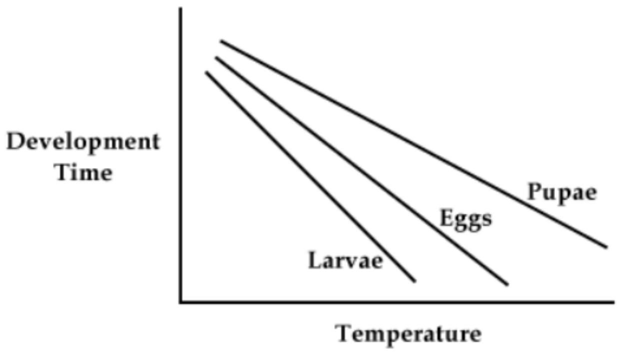
Temperature and consumption of Food Reserves

- When only limited quantity of food is available, the rate of consumption of food reserves is also dependent on the temperature. This in turn affects the survival of the insect. For example *Glossina spp*. fly depends on food reserves between two meals. If after one meal the food reserve is completely consumed and the fly does not get another meal immediately it will die.

Reproduction and Development

- The effect of temperature on reproduction and development rate vary within the species and between the species. The insects fertility its development ceases beyond the tolerable temperature range for reproduction and development. Within the tolerance range the development of eggs, the rate of oviposition, and larval and pupal development normally increase with the increase in temperature. Some interesting examples are of *Pediculus* which does not lay eggs below 25 ^{D} C and *Tenebrio molitar* which shows a considerable decrease in the pupal period with the increase in temperature within tolerable range.

- Within the optimum temperature range during which the reproduction and development ranges are maximum. Under fluctuating temperature the development rate is higher than under constant temperature, for example the eggs of grasshoppers. Such a situation is common under field conditions. The moulting process in insects is also affected by temperature. In some insects the number of moults increases at high temperature whereas in other it decreases. For example at a temperature of about 22 ^{D} C, 6 moults are recorded but at 32-37 ^{D} C there are only 7 moults by grasshopper.



Graph shows the relationship between temperature & development time of insects.

13.4 Relative Humidity (Moisture)

Environmental moisture factors are continuously variable. Therefore an insect has to face the extremes of these changes. All moisture factors also vary from time to time and spatially. The different factors related to moisture includes precipitations, humidity, condensation and available surface water. Snow fall provides solid precipitation whereas rainfall is the most common fluid precipitation. This depends upon air movement and the topography of the regions. These factors saturate the atmosphere with water vapour which results in the condensation through dew, fog and frost. All these factors cause the creation of dry and wet regions with many gradations between them. The amount of water vapour present in the air is considered as humidity which depends on the atmospheric pressure and temperature. For example there is always variation in relative humidity in different locations, time of day or year, topographical situation etc.

The various factors of Insects influenced by moisture are as follows-

Body Water Content

- Water is a important for life. The different insect's metabolic activities are dependent upon water. A suitable balance is always maintained between the water content of the internal environment of the body and the moisture present in the external environment of atmosphere which includes humidity and rainfall.

- In insect body the water content varies from insect to insect from less than 50 percent to more than 90 percent of total body weight. Caterpillars comparatively have larger amount of water whereas the insects with hard bodies have lesser amount of water. More water is present in the active stages in insects in comparison to inactive stages.

Water Source

- The main source of water is food for most of the insects. The quantity of water depends on type of food intake by insects. Those feeding on the succulent tissues of the plants have sufficient water whereas those that feed on dry food have little water. For arid zone insects the main source of water is obtained from metabolic process in the body. Some insects obtain water by absorbing it from the soil and atmosphere. The terrestrial insects living in dry areas obtain water by oxidation of the food within the body. Even fat is oxidised to produce water under certain conditions. The water from metabolic wastes is also utilized by *Tenebrio molitor*.

Insect Mortality

- Insect mortality is dependent upon the moisture in surroundings. There is always an optimal range of moisture which is suitable for insects. Excess of optimal range kill the insects. At extreme low moisture the active stages of insects in particular are killed. Mortality also occurs at extreme high moisture. The death at extreme low temperature is due to excess loss of water and at high temperature the causes for death are variable, such as spread of viral, fungal and bacterial diseases etc.

Longevity

- Environmental moisture determines the survival and length of life of insects. It is adversely affected by excess moisture. For example *Locusta migratoria* live longer at lower humidity.

Feeding Behaviour

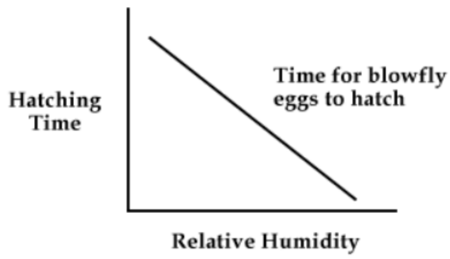
- At extreme moisture content in the environment the feeding activity of the insects is hindered. The larvae of spruce budworm stop feeding in water saturated air. The *Tsetse* fly does not feed at a relative humidity of 88 percent.

Reproduction

- Insect reproduction is also affected by moisture presence or absence. Excess moisture contents affect the reproduction. The Oviposition rate is adversely affected by low humidity. Infertility is shown by newly emerged adult migratory locusts, when relative humidity is below 40 percent.

Insect Development

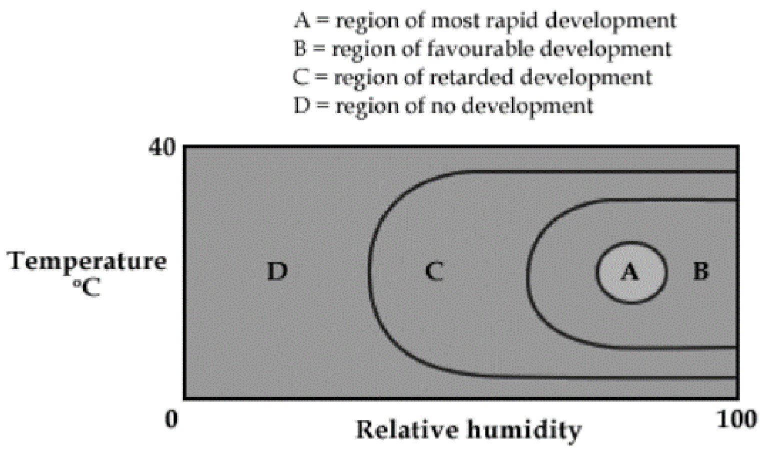
- Insect development and moisture relation is specific to species. The high moisture content decrease the rate of development which may even be completely halted. On the other side the silkworm larvae do not pupate at higher humidity. The incubation time for eggs is reduced at higher humidity for example in spider beetle. The developmental stages prefer higher humidity.



Graph shows the relationship between humidity and development time for blowfly eggs.

Combined Effect of Temperature and Humidity

- Insect interaction is always shown to a large extent between the effects of temperature and humidity. The humidity exerts a relatively greater effect on insects at the extreme temperatures and vice versa. For example, the boll weevil can survive in the high temperatures at comparatively low humidity as compared to high humidity. The same temperature has different effects at different humidity. Both temperature and humidity ecologically are interlinked.



Graph illustrates the interaction between temperature, moisture and insect development.

Light

Light is very important factor for insects. Its different parameters like photoperiod, illuminance, wave length, intensity etc. affects various activites of insects more or less. Rarely, the light acts as a lethal factor. The reactions of insects to photoperiod light and other parameters vary between the species and between different life stages of the same species.

Factors of Insects influenced by light

- Light has a great influence on the different factors of Insects like the swarming, egg laying, changes in flight, prolongation of life, the emergence of many species, stimulating effect on insects etc. For example the light stimulates egg laying in Praying Mantis and some other insects whereas it inhibits Oviposition in case of *Periplaneta.*
- The diapause is stimulated by the photoperiod. The feeding mating etc. are regulated by the daily circadian rhythms with dawn and dusk periods in between which functions as a biological clock.
- The plant feeding insects have senses of different wave-lengths of reflected light for host location. The direction of movement is affected by the position of sun and degree of polarization of light in different parts of the sky.
- Many insects are dependent upon plants for their food. The light have indirectly impact on the insects by affecting both terrestrial as well as aquatic plants. In aquatic ecosystem the main source of food are plants, the amount of light affects the photosynthesis in plants, and releasing

more oxygen, the aquatic insect life depends on the oxygen concentration in water to a very great extent.

Air and water currents

- Insects are influenced by both air and water currents. These are determined by geographic conditions of particular insect habitat.
- The insect mortality is caused by the air movement. Severe winds may cause mortality. The movement of air also kills the insects due to desiccation. However when the humidity is high the movement of air is beneficial.
- The distribution of several insects such as leafhoppers, aphids and many more insects is also influenced by winds. Sometimes wind is helpful in their dispersal while sometimes many insects are also killed by the strong winds by moving towards unfavourable environment.
- Water currents determines the existence of insects in different areas. The insects adapt themselves to face the water currents, for example Caddis flies get attached to submerged objects by their cases. The mosquito larvae and some other aquatic insects fail to survive in moving water. The black fly larvae get attached to stones or other material in water.

13.5 Biotic Factors

The influence of living organisms is said to be biotic factors. These factors have a profound influence on vegetation not only by their direct interaction but also through their effect on soil and therefore determine the nature of vegetation that can exist in a place. Biotic factors can be plants, other insects, wild animals, man etc.

Ecosystem existence is based on an effective interrelation between the insects and the biotic components. If the interaction is between the members of the same species it is called as intraspecific interactions and if the interaction is between the members of different species of insects it is called as interspecific interaction. Insects are also interrelated to plants as well as man. Interrelations of the insects to living environment are for the advantage of the insects.

Intraspecific Interactions

The main advantages of intraspecific interactions are high population density include availability of mates and the survival of potential predation. Intraspecific competition becomes more prominent when the availability of limited sources and when there is competition for same needs. These include associations for reproduction such as for mating, competition, pupation, parental care and cooperation, aggregation, colonial and social life.

Competition

Same species individuals lives in the same habitat, with similar requirements for food, protection and reproduction. There is a very tough competition for limited resources amongst them. The competition for food is very tough. Such a competition is disadvantageous to whole population. The fast feeders develop faster and may survive at the expense of slower individuals. The rule in the nature is survival of the fittest and weaker members are eliminated.

Sex relations

Sexual dimorphism is shown by different insects. In most of the insect species the males and females are of different sizes but in some species both are of equal size. Generally females have to breed, nourish eggs and young ones, therefore they are larger in size than males. And males members role is only to fertilize females or eggs, therefore they are smaller in size. Sexual ratio is also different in different species. In some it may be equal in number whereas in others they may be different in ratio. In aphids population males are absent.

Reproduction

In insects population pheromones plays a very important role in reproduction. Pheromone that serves as a chemical attractant to attract the other sex. The production of pheromone leads the insects to mate, copulate and reproduce. Moths depend on odour to seek their mates. Mostly nocturnal insects such as crickets make use of auditory signals to find out their mates. While some insects depend on visual stimuli to seek their mates. For example the male flies of the family Dolicopodidae, fire flies also depend on visual stimuli for finding their mates. The male flies flashes its lantern rapidly and the female sitting nearby glows at intervals. The light serves as visual signal. Among diurnal insects the colours and peculiar patterns are used for attracting mates. In tree cricket the male with upraised wings and loud singing approaches the female.

Parental care

Parental care in insects ranges from covering eggs with a protective coating to remaining to feed and protect young, to forming eusocial societies with alloparental care and lifelong associations of parents and offspring. Most commonly, care is provided solely by females; males rarely care for eggs and young alone, but in some cases males and females form long associations to rear young to adulthood. Various forms are widespread taxonomically and care is most developed in Hemiptera (true bugs), Thysanoptera (thrips), Embiidina (webspinners), Coleoptera (beetles), Hymenoptera (ants, bees, and wasps) and Isoptera (termites).

Parental care is exhibited by almost all the different species of insects. The variation is only of degree. Some exhibit parental care of a very high degree others simply just care for the offspring. The parental care varies from providing the shelter and suitable conditions for the development of the eggs to nursing, feeding, guarding, watching etc. of eggs, larvae, nymphs and imago. Almost complete care to the offsprings is provided by some insects.

The care of the eggs, laying of eggs at a suitable place having optimum conditions for incubation, sufficient food for the young ones and proper protection from the natural enemies. To provide protection, the eggs are hidden in crevices in walls, furniture and other household objects, underside of the leaves, stem tunnels, hollow seeds and fruits, under the bark and stones, underground and others. Some insects like lepidopterans glue the eggs to some objects, while others provide protecting cells or silken web made of various materials etc. The examples are ootheca of the praying mantid and cassididae, the former is made of solidified foam and the latter of faecal pellets. Some insects protects their eggs as well as larvae by preparing brood nest in which they also store food for them.

Some insects are very clever. They do not build their own nest but deposit eggs in the nest of other insects where the newly emerged larvae feed on the food stored by the insect that had built the nest. The example is of robber fly. It drops her eggs on the housefly paralysed by a wasp which he carries to his nest as food for the larvae. The beetle larvae cling to the hairs of the bee and along with it move to its nest where they feed on the nectar as well as the eggs of the bee. Some insects like cuckoo wasp leave their eggs in the nest of several other bees. Such habit has also been exhibited by robber and certain parasitic bees.

Forms of parental care

Maternal Care

The most rudimentary form of maternal care is provided by females that incorporate toxins into their eggs, oviposit them in protected places, or cover their eggs with a hard shell or wax-like compound before abandoning them For example, embiopteran webspinner females, *Antipalurai urichi*, cover their eggs with layers of macerated bark and other substrate materials and silk to protect them from hymenopteran parasites. Many species of insects guard their young against predators by using chemicals or defensive behaviors. Care may end when young hatch, or it may extend until larvae or nymphs are mature. For example, eggplant lace bugs, *Gargaphia solani*, guard their eggs and gregarious nymphs until maturity; if a predator approaches, the female rushes at it, fanning her wings.

A second major function of maternal care is to facilitate feeding. A plant-feeding membracid bug, *Umbonia crassicornis*, cuts slits in the bark with her ovipositor to facilitate nymphal feeding. She remains with the nymphs, actively maintaining feeding aggregations until the young reach adulthood. Parental care often comprises a suite of adaptations of multiple behaviours that serve multiple functions. A well-cited example of a complex of behaviours is the female salt-marsh beetle, *Bledius spectabalis*, which maintains a burrow shaped in a way that prevents flooding during high tide. She also provisions the young with algae, prevents mold, and protects the vulnerable first instars from attack by parasitic wasps.

The oviparous German cockroach, *Blattella germanica*, carries her egg sac externally until nymphs hatch, and *Blattella vaga* produces maternal secretions on which her neonates briefly feed. In ovoviviparous species, eggs develop inside the body of the mother and have sufficient yolk to complete development. The viviparous cockroach, *Diploptera punctata*, displays a remarkable form of parental care. Females undergo a 60-day "pregnancy" during which highly nutritious milk, secreted from the walls of the brood sac, is ingested orally by the developing young. At birth, young are in an advanced state of development, and care is terminated shortly after birth.

Paternal Care

Paternal care of eggs or young is restricted to about 100 species of insects, almost all within the Hemiptera. For example, in a giant water bug, *Abedus herberti*, females adhere their eggs to the wing covers of a male, who stops feeding and instead spends his time until eggs hatch aerating and protecting them from predators. Males of the subsocial spider-hunting wasp, *Trypoxylon superbum*. are an unusual example from the Hymenoptera. After females provision and seal the cells, males remain to guard nests against parasitism and ant predation. Males may care their offspring with nutritional offerings. They may transfer proteins or protective substances in a spermatophore. Male katydids, for example, provide a spermatophore during copulation that may be as much as 40% of their body mass; spermatophore nutrients have been shown to be important to the reproductive success of females. Male arctiid moths, *Utetheisa ornatrix* provide a different sort of indirect paternal contribution when they transfer protective pyrrolizidine alkaloids to females during mating. These alkaloids are passed to the eggs, which are then unappealing to predators.

Biparental Care

In case of biparental care both male and female members cares for offspring. This type of care is restricted to beetles, termites, and cockroaches, and may include earwigs. It can be very elaborate and extensive. For example, the woodroach, *Cryptocercus punctulatus*, and all termites form life-long family associations. Male and female construct and guard an extensive tunnel system or a nest, and they protect and facilitate feeding of young until the offspring reach maturity. Woodroaches care for a single brood for 3 or more years, feeding them on hindgut secretions containing symbiotic fauna necessary to digest their wood diet. In many of the "higher termites," (e.g., Rhinotermitidae and the Termitidae), few or no workers or soldiers reproduce; rather, they remain as alloparents. In the burying beetle, *Nicrophorus orbicollis*, males commonly remain in the nest until larvae are half-grown and the carcass is substantially consumed; females remain until larval development is complete and may even accompany larvae during the wandering stage. As with most species with biparental care, male and female burying beetles do not have exclusive, specialized tasks.

Cooperation, aggregation, colonial and social life

Cooperation

Animals have a tendency to cooperate with each other. Insects also cooperate with each other for different activities of the life. Initially insects Cooperates, then aggregates after this they becomes colonial and finally start living social life. Cooperation is considered as a compulsory part in the society. Without cooperation, the division of labour cannot be successful. The example of cooperation is provided by certain insects. A best example of cooperation is seen amongst ants. A worker ant while bringing the food, guides to its fellows the number of workers required to carry the food discovered by it. In case of injury they also show cooperation by carrying the injured fellows and also lick and clean their fellows.

The wasps collect and seal the food with the eggs. Some wasps continue to be with the eggs and assist the larvae in feeding. The wasps provide not only entire ordinary food but the specially prepared food also to the larvae.

Aggregation

For the profit of each other or for self only, the insects assemble in groups. The collective living may be on a permanent or temporary basis. Insects usually aggregates for defence from enemies, for breeding, for feeding, due to similar or limited habitat, because of the division of labour some animals, although independent individually, live together, due to responses to unfaviourable conditions, visual stimuli etc.

Colonial life

Insects shows some extent of the division of labour which lead to a colonial life. Colonies are organised group of individuals showing considerable specialization towards division of labour and cooperation.

Social life

Some insects like the termites, bees, wasps and ants lead a social life. The social insects exhibit the division of labour, cooperation and polymorphism. Social insects live in the colonies comprised of a large progeny, the individuals of which live together along with the mother. The works of the colony like feed collection, defence, care of the eggs, larvae and pupae are taken over by newly emerged progeny leaving mother for enlarging the nest and egg laying.

The ant colonies shows the most developed social life behaviour, their number varies from dozens to millions. The colony includes polymorphic forms and is developed by the fertilized queen or by the migrants of an initial parent colony. The sites of the colony include underground, under stones, in the open, in the trees and various other places. The workers collect the food for the colony. Like termites several species of ants cultivate fungi. A tendency of mutual feeding i.e. division of food between the individuals of a community is also developed amongst them.

The termites construct the termitarium with various facilities like controlled temperature and defence against predators and harmful fungi. The social organization of termite includes queen, the sexually matured female and her progeny which is comprised of mature males and sterile females (workers and soldiers). The colony lives in the nest which is composed of a queen chamber in the centre and many galleries with ventilators. The colonies are found in humid situations under stones, in the wood and on the wall of buildings. The vegetable matter collected by the workers forms the food of the colony. The larvae and queen feed on specific secretion by the workers. The *Ambrosia* fungus is grown in the fungus gardens in the nest which is used as a food.

The social structure in bees includes a single fertile female or queen bee along with a large number of sterile and winged workers, the females. The colony dwells in a nest made of wax combs. The workers collect the food which consists of pollen and nectar. The social structure in wasp is somewhat different from termite colony. It includes one or more queens and workers which are sterile and winged. The colony dwells in a nest made of wood pulp. It is comprised of numerous cells which are arranged in combs.

Pollution

If the population is high then their outcome will also be high, as a result there will be a pollution. For example in case of densely populated flour beetles huge pollution is caused by their metabolic wastes.

Interspecific interactions

Interspecific interactions takes place between different insect species like competition, commensalism, symbiosis, parasitism-host interactions and predator-prey interactions.

Competition

The interspecific competition between two or more different species is due to overlapping of their niches means when they have common needs for food, shelter, or any other resources. In such a situation no two species can occupy the same niche at the same time for very long, fittest species will capture the resource and eliminate the other weaker species. In the competition for food, a small species requires less food, they usually have an advantage over a large species that requires more food. Similarly a species that completes development in short time has an edge over a large species that takes a longer time. Competition is chiefly for food. If this food is sufficient just for one, then out of two individuals who will compete, only one will be winner.

Commensalism

Commensalism term was coined by Van Beneden for the animals who share common food. In this type of association one or more than one insect species may be benefitted but others are not injured or even affected adversely. In a way a species tolerates the presence and act of others. An example of commensalism is rat, in whose nest a large number of different types of insects take shelter.

Symbiosis

It is an association of different insects and other animals for mutual benefit. All the associates are called as symbionts and are benefitted. Symbiotic relations among different insects and other animals are established for different interests such as for food, protection, luxuries of life and even by accident. An interesting example is of a certain beetle that lives in the termite nest and gives off some secretion through a glandular knob of the abdomen. The secretion is continuously licked by termites. Symbiotic relations between ants and termites with several animals have been reported by several entomologists, for example nesting of many birds in association with wasps, ants and termites giving mutual protection. Ants have been reported to care for and receive food from aphids, membracids and scale insects.

Parasitism – host interactions

Parasitism is the association between two or more different animals in which one is benefitted and the other is harmed. In size a parasite is always smaller than its host. Parasites are dependent on hosts for food, shelter and protection. A parasite gives nothing in return to host. It becomes so much dependent on the host that it is rendered incapable of independent existence. A parasite does not kill the host but continuously feeds on the living substance for whole life. Various groups of animals are parasitized by the insects. They may even parasitize fellow insects. Parasitism is common in insects of the orders Neuroptera, Hymenoptera, Strepsiptera, Diptera and some Lepidoptera.

Types of parasites

- Ectoparasites -Those live externally on the host.
- Endoparasites -Those live within the host body.
- Facultative parasites-Those which need not to lead such a life. These may have life apart from the host.
- Obligatory parasites-These parasites can exist only when in close association with their usual hosts.
- Permanent parasites-Those parasites continually remain associated with their hosts.

- Transitory parasites-Those come in contact with their hosts occasionally or during certain stages in their life histories.
- Social parasites-Those attack societies and live at the expense of community.
- Accidental parasites-Those which are normally not parasites but due to some unusual circumstances become associated with the hosts.
- Monogenetic parasites-Those having a simple life history and all stages associated with a single host.
- Di- or Tri- genetic parasites-Those having alternation of generations and relations with two or more hosts.
- Temporary parasites-Those live a free life for some time.
- Hyper-parasitism-A parasite of an insect is itself attacked by another insect parasite.
- Multi-parasitism-In this case a host is attacked by several different species of parasites.
- Super-parasitism-In this case different individuals of some species attack the same individual of the host.
- Clepto-parasitism- is a kind of social parasitism which involves robbing.

Examples of parasites

Ectoparasites include mostly the blood sucking insects. These include lice infesting bats, and bed bugs, mosquitoes, fleas etc. which do not stick permanently on any host.

Insect parasites that are parasitic on other insects include predatory wasps and other insects that paralyze the host by stinging. They even lay eggs on them. The larvae feed on paralyzed host.

Some of them deposit eggs within different developmental stages of various insects. The larvae develop on these stages and finally kill them. Such a parasitic mode of life remains confined to the larvae and the adults lead a free life. Insects having such parasitic mode of life are met in the orders Hymenoptera, Diptera, many Neuroptera and some Lepidoptera.

Example of Hyper-parasitism is provided by a species of the Chalcid Perilampus which are often parasitic on the Ichneumonoids which are parasites of caterpillars of Lepidopetra. Ectoparasitism is common among hyper-parasites.

Clepto-parasitism is shown by bee lice that invade the nests of bees and consume the food stored by them. Social parasitism is seen amongst ants. The ant Anergates invades the nests of Tetramorium to take away the brood to its own nest.

Interactions

Insects are the organisms that parasitize insects, micro-organisms, mites and nematodes. Microbes and nematodes parasitize both insects and vertebrates. These insects play an important role of vectors carrying parasites to their vertebrate hosts. Microbes gain entry into insect either by penetrating the integument, or orally or through wounds. They may even pass on to offspring via eggs in some instances for example arboviruses in mosquitoes.

Bacillus thuringiensis is the best known bacteria that infects the insects. It forms the spores and is also used in bio-control. *Bacillus* larvae causes serious disease of honey bee larvae. Amongst other insect pathogens are *Clostridium* and *Streptococcus.* Insects also transmit certain bacterial pathogens of vertebrates for example rat flea causes plague in human.

Many known viruses have been found in insects of the orders Lepidoptera, Diptera, Hymenoptera, Neuroptera and Coleoptera. It has been found that a virus or a bacterium separately fails to produce a disease syndrome but the same is produced when a virus acts in conjunction with a bacterium, for example two diseases gattine and flacherie in silkworm involving *Streptococcus bombycis* and *Bacillus bombycis* respectively. Several viruses such as arboviruses, and those that cause yellow fever, encephalitis and dengue are carried to humans and other vertebrates by the insect vectors.

Amongst microbes, fungi include maximum species which are pathogenic to insects. Fortunately insects are not the vectors of those fungi that cause diseases in human and other vertebrates. Insects are the vectors of fungi pathogenic to plants.

Different protozoans of the group sarcodina, Mastigophora, and Sporozoa are insect pathogens. *Nosema apis* is pathogenic to silkworms and honey bee. Some protozoans found in the gut of termites helps in the digestion of cellulose by providing cellulase to their host. Insects also act as vectors for several protozoa pathogenic for humans and other vertebrates for example *Plasmodium spp*. causing malaria is vectored by *Anopheles* spp. mosquitoes. Other examples include *Tsetse* flies, the vectors of *Trypanosoma gambiense* and *T. rhodesiense*, causing African sleeping sickness and blood sucking bugs of the order Hemiptera, the vectors of *Tryanosoma cruzi* that causes "Chagas" disease.

Numerous nematodes are also associated with many insects. These are entomophilic nematodes that cause damage which is followed by death of the insects. Nematodes have also been found useful in insect bio-control. Some attack humans also, for example *Wuchereria bancrofti* (filarial worms). Amongst gall inducers, besides fungi, nematodes, mites and other organisms, the insects are the most common ones. Some specific galls are caused to develop by the insects.

Predators-prey interaction

Predator is an organism that eats another organism. The prey is the organism which the predator eats. Predator and prey evolve together. The prey is part of the predator's environment, and the predator dies if it does not get food, so it evolves whatever is necessary in order to eat the prey: speed, stealth, camouflage (to hide while approaching the prey), a good sense of smell, sight, or hearing (to find the prey), immunity to the prey's poison, poison (to kill the prey) the right kind of mouth parts or digestive system, etc. Most common relation between different species is that of predator and prey. Among insects, the predation is considered as the most primitive mode of feeding. Predaceous species are always less in number as compared to herbivorous animals and scavengers to avoid the extermination of the prey.

Prey capturing

The predator insects safe their prey by different ways. Odonates capture the preys on wing and praying mantis by lying in wait. The predators usually hunt by using their sense organs except antlions that capture by snaring the prey in pits or in webs for example Trichoptera. Cicindellid beetles secure their prey by springing, water striders by gliding on the surface of water, carabids by running down and dytiscids by swimming. In certain other insects such as Nepa, Mantispa etc. the forelegs are modified as raptorial appendages armed with spines and teeth.

Predators of insects

All the predators are found in abundance and consume a very large number of insects thereby exerting a natural force against insect population and regulate them. The main predator examples of the insects are mites, spiders, scorpions and pseudoscorpians amongst arthropods and fishes, amphibians, reptiles, birds and mammals amongst vertebrates. Insectivorous plants, such as pitcher plant, venus flytrap, bladderworts and sundews also trap and digest the insects. Man also use the predators to sustain the insect population.c threshold.

Predators like the beetles of the families Carabidae and Staphylinidae feed on both larval and adult stages. Other predators are nclude, wasps, larvae of certain families of Diptera such as Tabanidae, Dolichopodidae etc. nymphs and adults of damsel flies and dragonflies, certain hemipterans such as assassin bugs (Reduviidae), ambush bugs (Phymatidae), plant bugs (Miridae) and many other insects. Predatory anthocorid bugs on entering the galls feed on a few aphids present therein but those not attacked by them also die. Their death ensues by the funigant effect of chemicals which are produced by the stink glands of the bugs.

In vertebrates, may fishes, sun fish, perch, sheepshead, *Gambusa*, feed on insects. Reptiles and amphibians are very common insect feeders. Predaceous mammals include mice, shrews, skunks, ant eaters, bats and moles that consume large number of insects. Many birds eat insects. Amongst birds, fly catchers, night hawks, robins, wrens, cuckoos, quails etc. are outstanding insect eaters.

13.6 Population dynamics

Population dynamics is the branch of life sciences that studies the size and age composition of populations as dynamic systems, and the biological and environmental processes driving them (such as birth and death rates, and by immigration and emigration).The study of population growth and its causes is population dynamics. The growth may be positive or negative resulting into rise or fall in the number of individuals in a population. To understand the fluctuations in a population, different types of sampling methods are used. Sampling is the process of selecting participants from the population. The target population is the total group of individuals from which the sample might be drawn.

Different Methods for Sampling

Insect population in a natural habitat is dense, it is not feasible to determine the density of population just by counting. It can be done by dividing the whole observing area into small units, called samples. These samples are then analysed and the insect population is estimated in the vast area on the basis of number of individuals in different samples.

Systematic sampling

- When the habitat is homogeneous, the sampling is done by dividing the area into different units or samples having uniform spacing between them.

Random sampling

- When the habitat is heterogeneous the area is divided into units or samples in a random fashion.

Selective sampling

- In this case known insects which are habitants of certain locations in a sample area, the samples are picked up by selective sampling as the efficiency of sampling is increased by the selection of such locations. If the effect of different ecological factors in an area is to be assessed, the selective sampling is done. For example the samples are taken from the locations with a particular vegetation in a vast area.

Actual Count

- Actual count means the calculated count in different samples areas of population of insects in the whole area.

Relative count

- It means comparison of the count of two different areas. When the population in two areas is to be determined on a relative basis i.e. one area is with more or fewer insects than the other area, the sampling procedure includes the determination of the number of individuals for a given period of time in both the areas.

Population estimation by indirect methods

The population can be indirectly estimated by observing the different activities of the insects and not the insect counts. The activities may include different types of crop damages, defoliated leaves, injured field crops and fruits, faecal pellets, empty cocoons etc.

Population Growth

When there are favourable conditions, there will be a remarkable rise in the population which may even reach to millions, if the fecundity of female insect species is full and there is no mortality in all the young ones. The relationship between the population size and time is simple exponential. Total eggs laid by a female insect species have 50 percent females, then the population of the offspring in 20 generations will exceed millions. All the insect species will increase and reach the huge number if the environmental conditions are optimum and favourable. But in reality this is very rare that the insect species attains full fecundity and complete survival of young leading to maturity even when there are favourable environmental conditions. In environment the favourable conditions are not constant they are variable. because both biotic and abiotic factors in an environment varies from time to time and a population on reaching the high density itself creates adverse conditions making the environment unfavourable. The unfavourable environment factors reduces fecundity and also causes mortality in different developmental stages. The stages in the life cycle, if escape death, show poor growth and ultimately die. Thus the population of insects in different generations keep fluctuating. It may be increased in one year and decreased in other years but returns back to normal over a period of several years.

Natural Balance

The balance of populations of two successive generations is maintained by the mortality ratios of balance which varies from species to species. It is directly proportional to fecundity. There will be a fall in the population if the mortality ratio becomes higher than that for balance. The relationship implies that the mortality may be higher or lower than the ratio of balance in different years but ultimately the long-term mortality ratio comes to the balance level. This phenomenon is known as the natural balance.

Causes of Population Fluctuations

- Fluctuations in insect population is mainly caused due to the changes in environmental conditions but these changes depends on the sensitivity of the insects.

Sensitivity to Individual Environmental Factors

- Insect species are sensitive to particular environmental factors. A fluctuation in such factors causes a variation in the population of that particular insect species.

Sensitivity to collective environmental factors

- Insect species are influenced by different environmental factors collectively. In such cases a change in one or the more factors of the group to which a particular insect species is sensitive causes fluctuations in its population. The insects exhibit frequent fluctuations which may be irregular and cannot be predicted.

Sensitivity to individual large number of environmental factors

- Few insect species are sensitive to one or few factors but are tolerant to most of the factors. In such cases it is possible to predict fluctuations based on the degree to which such factors favour fluctuations. These are known as key factors.

Magnitude of fluctuation

- In case of small magnitude population species are able to tolerate most of the environmental factors continuously while big magnitude leads to population crash. This may be due to high rates of parasitism, food shortage, epidemics of disease etc.

Balance with the Environment

The population of different insects is kept balanced with the environment at different population levels. The various factors behind this environmental balance are such as natural enemies, genetic change, food, habitat, mortality etc.

- **Natural enemies**
  Many insect species shows population growth at exponential rates due to favourable environmental factors due to absence of natural enemies in the area. As soon as their natural enemies are introduced in the area their population shows a declination.

- **Genetic change**

  The natural selection results in the genetics structure changes of a strain. Since the change tends to be an adaptation to a favourable environment a high level of population is maintained. A limiting factor is that which limits the population even if all other factors are favourable, would improve and bring a remarkable increase in the population, for example increase in soil moisture for wire-worms. On the other side it can acts also as a degradation factor in spite of other factors that remain favourable as shown in the effect of resistant wheat varieties on Hessian fly.

- **Food**

  If suitable food is available for feeding then insect species may increase extremely in number to the extent that it becomes a pest. They may even extend their distribution. In such situation the insect species maintains a balance with the environment at a high density. For example Colorado potato beetle.

- **Habitat**

  Habitat fluctuation may also influences the population density. For example good irrigation of crop lands may increase certain insects number and become a major pest like wire-worms. Oxygen concentration in water influences the population of Mayflies, they increases in more quantity of oxygen but may be reduced by the eutrophication of rivers and lakes whereas the population of Chironomids increases in low concentration of oxygen.

- **Mortality**

  Mortality factors exert different effects on population dynamics, having different characteristics.

  There are three main causes for mortality in the insect population.

  1. Mortality due to shortage of food and other resources.
  2. Mortality caused by natural enemies.
  3. Mortality due to severe physical conditions which insects fail to tolerate.

- Consistency – The consistency of different mortality factors may be different. The variable factors are more effective and crucial than the constant factors.
- Specificity – Different mortality factors may differ in specificity. For example, if a general parasite attacks before the specific parasite the mortality will be higher.
- Density relationship – The density relationship of different mortality factors may be different. The factors that are density-dependent cause higher mortality with the increase in insect density. The factors that are density-independent cause constant mortality regardless or insect density.
- Effect on different insect stages – Different stages of insects may be affected by mortality factors.

There is need for designing the insect management programmes which must have an ecosystem approach. The study of population dynamics shows the ecological relationship of insects with their environment,

Host plant insect interactions

Approximately 30 -40% of all insect species feeds on plants and the remaining ones are carnivores, parasitoids, parasites, saprophages etc. In other words plant feeders are "parasites" of plants. Plants don't move so insects have to come near plants. Insects use all parts of the plant as food but there is not a single insect species which can consume all plant parts.

Leaves

a) Feed from/on surface

Leaf feeders (whole or portions of leaf)- e.g. Colorado potato beetle, grasshoppers, lepidopteran larvae, leaf feeders (skeletonizers), beetle larvae.

Sap suckers – These types of insects have a piercing and sucking type of mouth parts which help to enterinto individual cells or vascular system of plants. - aphids both direct and indirect damage.

The insects can assimilate plant and spread plant diseases. Any insect that moves from plant to plant may spread disease.

b) Feed inside- leafminers - serpentine, blotch mines, protected by leaf tissue, implications for control. E.g. - caterpillars, fly larvae, sawflies - birch leafminers.

Stems/Stalks

Insects can cause excessive damage to stem parts of plant with limited feeding.

a) Feed from/on surface - cutworms - also feed just below soil surface and on foliage, aphids etc.

b) feed inside -bark beetles – stem, stem or stalk borers - major pests in corn, also were in wheat.

Roots

Its usually very difficult to detect root insect infestation**.**

a) feed from/on surface - fly larvae - roots (cabbage maggots) also provide wounds, beetle larvae - wireworms - root damage, aphids - phylloxera.

Reproductive Tissues -Pollen feeders insects usually acts as pollinators, and seed eaters.

Factors which influence insect host plant interactions

1. Low nutritional quality (available nitrogen).

- Lower protein content than animals.
- Different ratios and proportions of amino acids, salts, etc.
- Phytophagous insects often have low assimilation and growth efficiencies (study: 2% - 38%).
- Assimilation and growth rates can be linked with plant nitrogen content:
- Effects of fertilizer- from increasing nitrogen content, overall many insects show "better" growth with increased nitrogen but not all.

2. Physical defences

- hooks, spines, trichomes - sticky exudates
- leaf toughness
- can be age-related (of plant). e.g. pubescence may increase with age.

3. Plant environment

- Plants in absence of phytophagous insects may flourish in a wide range of conditions. E.g. Klamath weed (introduced to North America). *Hypericum perforatum*
- Widespread plant in drier sunny exposure; acceptable to beetles (beetles destroy it). *Chrysolina spp* found in moist, shaded area - less or barely acceptable to beetles.

Plant chemistry

Plants contains various biochemicals that were used as medicines and poisons against insects

- **Loaded with bioactive substances**
  - Drugs/medicines - morphine, quinine.
  - Insecticides-pyrethrum
  - Many appear to be defensive material (against insects)
- **Effects of bioactive substances**
  - Cause disease in insect.
  - Inhibit feeding, reduce growth and fecundity.
  - interactions of these organisms may be driving the co-evolution of these systems.
  - Coupled to assumption that all the major plant components **(primary compounds)** and their effects on insects are similar then
  - Minor components **(secondary compounds)** influence insect specificity.
    - E.g. Amino acids - influence aphids.
    - Acceptable part of the time - then move to new host.
    - Secondary plant compounds - play a major role in specificity.
    - E.g. Alkaloids - over 5,000 known, Glucosinolates, phenolics (tannins).
    - These can be repulsive, unpalatable, poisonous or interfere with nutrient assimilation.
    - Prevents feeding by most phytophagous insects.

- Some insects develop mechanisms to overcome defences
- These plants then serve as important food source.

Host-plant resistance

Nonpreference (Antixenosis)

- Variation among group of plants makes some plants unacceptable.
- Lack of positive stimuli.
- Behaviour of insect changes.
- Stem-borers - tougher stems may reduce insect success.

Antibiosis

- Consumption leads to disease/death.
- Presence of xenobiotics (physiological disruption).
- Most plant breeders manipulate these.

Tolerance

- Can tolerate greater amounts of damage.
- Plant variation.
- Compensatory growth.

Host Plant Selection

Insects with their well-developed sensory systems select their host plants-

- Long distance –
  - Vision attractive colour - limitations.
  - Olfaction - large number of volatiles like mustard oils, thiocyanates - generated from glucosinalates, crucifer feeders
- Close to plant - olfaction - leaf alcohols (different blends - insects may differentiate between host and nonhost.
- Arrives on host (or similar to host) - taste and olfaction

Insect Behaviour on Plant

Colorado potato beetle

- Squeeze leaf with mandibles (especially marginal host)
- Small bite - marginal host - may take several bites before rejecting
- Feed - detect stimulants - feeding.

- Similar process for Oviposition.
- Detects deterrents.

13.7 Biochemical adaptation against environmental stress (hibernation, aestivation, diapause, polymorphism, swarming)

Hibernation

Insects are well hidden in winter, but there are several locations in which they can reliably be found. Ladybugs practice communal hibernation by stacking one on top of one another on stumps and under rocks to share heat and buffer themselves against winter temperatures. The female grasshopper, family Tettigoniidae, in an attempt to keep her eggs safe through the winter, tunnels into the soil and deposits her eggs as deep as possible in the ground. Many other insects, including various butterflies and moths also overwinter in soil in the egg stage. Some adult beetles hibernate underground during winter; many flies overwinter in the soil as pupae. Other methods of hibernation include the inhabitancy of bark, where insects nest more toward the southern side of the tree for heat provided by the sun. Cocoons, galls, and parasitism are also common methods of hibernation.

During winter hibernation is a physiological condition of retardation or arrest of growth, primarily to overcome lower temperature conditions. For surviving many insects regularly hibernate in the egg, larval, pupal or adult stage. Many insects enters into the hibernating state even when it is quite warm. The eggs of grasshoppers are laid during early summer and are subjected during the summer and autumn to temperatures well above those at which the hatching occurs in next spring. The hibernating pupae of most Lepidoptera cannot develop and reproduces if they are exposed to higher temperatures. It is necessary to chill the eggs of most of the hibernating insects before the hatching. Even if hibernation can be broken by application of high temperatures, high mortality or abnormal individuals result. The hibernating pupae of *Mamestra brassicae*, exposed to high temperatures throughout the winter, do not show any considerable reduction of the pupal period.

For the insect normal development heat acts as a disturbing factor. The role of low temperature in winter is very important for stimulating factor on development. Hibernation is also associated with other complex factors like atmospheric humidity. It was observed that pupae of *Saturnia*, which hibernate, may be induced to develop by moistening them several times. When hibernating codling moth larvae is soaked with water it shows high degree of survival. The hibernating larvae of *Pyrausta nubilalis* are sensitive to changes in contact moisture. Desiccation during hibernation retards pupation in this insect. The termination of hibernation of the adults of *Epilachna corrupta* is influenced by precipitation in spring. In the absence of moisture insects shows the prolonged hibernation and high mortality. Sometimes an abundance of moisture may prevent hibernation. Reduction of water content of the body increase resistance to cold and may perhaps be also an immediate cause of dormancy.

Aestivation

This behaviour is shown by insects during summer season. Aestivation is a state of animal dormancy, similar to hibernation, characterized by inactivity and a lowered metabolic rate that is entered in response to high temperatures and arid conditions. It takes place during times of heat and dryness, the hot dry season, which are often the summer months. Insects are known to enter this state to avoid damage from high temperatures and the risk of desiccation. Both terrestrial and aquatic insects can undergo aestivation. Some insects have ability to remain dormant during unfavourable summer months when there is water scarcity or intense heat. In hot and dry places, insects are usually more abundant during spring and autumn than at the height of summer. During the extreme high temperature they aestivate even in the presence of moisture. Aestivation is also perhaps an inherited cycle, which cannot be broken within a single generation. Normally in insects, during summer the adults die but the eggs & pupae survive by remaining dormant.

Dormancy

Insects exhibit different adaptive mechanisms for surviving and anticipating the various changes in ecosystem, with reference to dormancy. Dormancy is occurred in embryonic, larval, pupal or adult stages of the life cycle and is generally distinguished as **quiescence** or **diapause**, depending upon its termination in response to changes in environmental conditions. Dormancy results in the retardation of development and growth or their total arrest. A variety of natural and artificial stimuli are capable of terminating dormancy. Most insects seem to have more than one mechanism for anticipating the return of favourable conditions. The nature of dormancy depends upon the nature and complexity of physiological, biochemical and hormonal conditions, determined in their turn by external environmental conditions. Dormancy is the result of variations of atmospheric temperature, and may be distinguished as hibernation and aestivation.

Quiescence

The term, first used by Shelford in 1929, is a condition of retardation of growth, induced directly by environmental conditions. The distinction between quiescence and diapause is difficult and is based largely on the relative speed of their termination. Quiescence may be considered as due to an abrupt, non-cyclic and brief deviation of environmental factors and may occur in any stage. There is no end of synthetic processes, but only slight slowing down.

Diapause

Diapause is a suspension of development that can occur at the embryonic, larval, pupal, or adult stage, depending on the species. In some species, diapause is facultative and occurs only when induced by environmental conditions; in other species the diapause period has become an obligatory part of the life cycle.

Diapause is the condition of dormancy for overcoming prolonged, cyclic and unfavourable environmental conditions and may be induced well before the onset of adverse conditions and even continue for some time irrespective of these conditions. Diapause is a spontaneous arrest of development and occurs at any stage of development. Auto-intoxication with metabolic wastes, enzymes and external factors have all been attributed to be important factors that determine diapause.

The diapause is a specific physiological condition, quite different from the arrest of activity often induced by unfavourable external conditions. Many insects interrupt their development at certain stages by a diapause, during which the development comes to a standstill, metabolism is reduced to minimum and the insect is wholly insensitive even to unfavourable external conditions. The diapause sets in, independently of external factors, at a definite developmental stage in each species. In addition to the species that undergo obligatory diapause, there are also others which undergo facultative diapause. The influence of external factors on some sensitive phase of development often determines whether diapause shall occur or not in such species. This sensitive phase lies far before the time of beginning of diapause. In the case of the silk moth it may indeed be a whole generation before. In all cases, the end of diapause is more or less pronouncedly influenced by external factors. Unlike the arrest of activity brought about by unfavourable external conditions, which disappears only when the favourable conditions return, diapause may end even under most unfavourable external conditions, such as, for example, in a period of cold. There are numerous gradations between true diapause and the arrest of development under unfavourable conditions. The adults of many beetles, overwintering in the diapause state, show atrophy of their gonads and hypertrophy of the fat body. In *Anthonomus grandis* there is an increase in the water content and a decrease in fat content in early spring and this is followed by the beginning of spermiogenesis. The oogenesis takes place only after the female has taken food. In *Letinotarsa decemlineata* the development of gonads begins at the end of diapause.

The end of diapause is brought about in different insects of different ways. In Lepidoptera it is ended by the previous action of cold, so that the brain influences the prothoracic glands. It is, therefore, the action of prothoracic glands hormone, which terminates diapause. The adult diapause of *Leptinotarsa decemlineata* is broken by the gonadotrophic hormone of the corporaallata. The egg diapause of the grasshopper *Melanoplus* is broken by the removal of the waxy-layer cover, thus permitting the penetration of water through the micropyle. The egg diapause of the mosquito *Aedes hexodontus* is not ended by absorption of water and not also be changes of the photoperiod but only by cold treatment. The egg diapause of the grasshopper *Acheta commodus* is also broken by the action of cold. It is, therefore, evident that not only the external factors but also the physiological mechanism is important in breaking diapause.

Phases of insect diapause

Diapause in insects is a dynamic process consisting of several distinct phases. While diapause varies considerably from one taxon of insects to another, these phases can be characterized by particular sets of metabolic processes and responsiveness of the insect to certain environmental stimuli. Diapause can occur during any stage of development in arthropods, but each species exhibits diapause in specific phases of development. Reduced oxygen consumption is typical as is reduced movement and feeding. In *Polistes exclamans* only the queen is said to be able to undergo diapause. The sensitive stage is the period when stimulus must occur to trigger diapause in the organism. Examples of sensitive stage/diapause periods in various insects

1. **Induction phase :** The induction phase occurs at a genetically predetermined stage of life, and occurs well in advance of the environmental stress. This sensitive stage may occur within the lifetime of the diapausing individual, or in preceding generations, particularly in egg diapause. During this phase, insects are responsive to external cues called token stimuli, which trigger the switch from direct development pathways to diapause pathways. Token stimuli can consist of changes in photoperiod, thermoperiod, or allelochemicals from food plants. These stimuli are not in themselves favourable or unfavourable to development, but they herald an impending change in environmental conditions.
2. **Preparation phase :** The preparation phase usually follows the induction phase, though insects may go directly from induction to initiation without a preparation phase. During this phase, insects accumulate and store molecules such as lipids, proteins, and carbohydrates. These molecules are used to maintain the insect throughout diapause and to provide fuel for development following diapause termination. Composition of the cuticle may be altered by changing hydrocarbon composition and by adding lipids to reduce water loss making the organism resistant to desiccation. Diapausing puparia of the flesh fly *Sarcophaga crassipalpis* increase the amount of cuticular hydrocarbons lining the puparium, effectively reducing the ability of water to cross the cuticle.
3. **Initiation phase :** Photoperiod is the most important stimulus initiating diapause. The initiation phase begins when morphological development ceases. In some cases, this change may be very distinct and can involve moulting into a specific diapause stage, or be accompanied by color change. Enzymatic changes may take place in preparation for cold hardening. For example, only diapausing adults of the fire bug, *Pyrrhocoris apterus*, have the enzymatic complement that allows them to accumulate polyhydric alcohols, molecules that help to lower their freezing points and thus avoid freezing. Insects may also undergo behavioural changes and begin to aggregate, migrate, or search for suitable overwintering sites.

4. **Maintenance phase :** During the maintenance phase, insects experience lowered metabolism and developmental arrest is maintained. Sensitivity to certain stimuli which act to prevent termination of diapause, such as photoperiod and temperature, is increased. At this stage, insects are unresponsive to changes in the environment that will eventually trigger the end of diapause, but they grow more sensitive to these stimuli as time progresses.
5. **Termination phase :** In insects that undergo obligate diapause, termination may occur spontaneously, without any external stimuli. In facultative diapausers, token stimuli must occur to terminate diapause. These stimuli may include chilling, freezing, or contact with water, depending on the environmental conditions being avoided. These stimuli are important in preventing the insect from terminating diapause too soon, for instance in response to warm weather in late fall. In the Edith's Checkerspot butterfly, individuals must receive enough sunlight in order to terminate the diapause stage and became a fully grown butterfly. Termination may occur at the height of unfavourable conditions, such as in the middle of winter. Over time, depth of diapause slowly decreases until direct development can resume, if conditions are favourable.
6. **Post-diapause quiescence phase :** Diapause frequently ends prior to the end of unfavourable conditions and is followed by a state of quiescence from which the insect can arouse and begin direct development, should conditions change to become more favourable. This allows the insect to continue to withstand harsh conditions while being ready to take advantage of good conditions as rapidly as possible.

Factors regulating diapause

Diapause in insects is regulated at several levels. Environmental stimuli interact with genetic pre-programming to affect neuronal signalling, endocrine pathways, and, eventually, metabolic and enzymatic changes.

- **Environmental Factors (External)**

Environmental regulators of diapause generally display a characteristic seasonal pattern. In temperate regions, photoperiod is the most reliable cues of seasonal change. Depending on the season in which diapause occurs, either short or long days can act as token stimuli. Insects may also respond to changing day length as well as relative day length. Temperature may also act as a regulating factor, either by inducing diapause or, more commonly, by modifying the response of the insect to photoperiod. Insects may respond to thermoperiod, the daily fluctuations of warm and cold that correspond with night and day, as well as to absolute or cumulative temperature. Food availability and quality may also help regulate diapause. In the desert locust, *Schistocerca gregaria*, a plant hormone called gibberellin stimulates reproductive development. During the dry season, when their food plants are in senescence and lacking gibberellin, the locusts remain immature and their reproductive tracts do not develop.

- **Neuroendocrine factor (Internal)**

The neuroendocrine system of insects consists primarily of neurosecretory cells in the brain, the corpora cardiaca, corpora allata and the prothoracic glands. There are several key hormones involved in the regulation of diapause: juvenile hormone (JH), diapause hormone (DH), and prothoracicotropic hormone (PTTH).

Prothoracicotropic hormone stimulates the prothoracic glands to produce ecdysteroids that are required to promote development. Larval and pupal diapauses are often regulated by an interruption of this connection, either by preventing release of prothoracicotropic hormone from the brain or by failure of the prothoracic glands to respond to prothoracicotropic hormone.

The corpora allata is responsible for the production of juvenile hormone (JH). In the bean bug, *Riptortus pedestris*, clusters of neurons on the protocerebrum called the pars lateralis maintain reproductive diapause by inhibiting JH production by the corpora allata. Adult diapause is often associated with the absence of JH, while larval diapause is often associated with its presence.

In adults, absence of JH causes degeneration of flight muscles and atrophy or cessation of development of reproductive tissues, and halts mating behaviour. The presence of JH in larvae may prevent moulting to the next larval instar, though successive stationary moults may still occur. In the corn borer, *Diatraea gradiosella*, JH is required for the accumulation by the fat body of a storage protein that is associated with diapause.

Diapause hormone regulates embryonic diapause in the eggs of the silkworm moth, *Bombyx mori*. DH is released from the subesophageal ganglion of the mother and triggers trehalase production by the ovaries. This generates high levels of glycogen in the eggs, which is converted into the polyhydric alcohols glycerol and sorbitol. Sorbitol directly inhibits the development of the embryos. Glycerol and sorbitol are reconverted into glycogen at the termination of diapause.

Polymorphism

Polymorphism (from Greek: *poly,* meaning "many" and *morph,* meaning "form") is a discontinuous genetic variation where two or more forms, stages, or types exist in the same species within the same population. It can apply to biochemical, morphological, and behavioral characteristics.

Polymorphism represents another level of specialization, above the level of cell, tissue, and organ specialization found in insects individuals, and below the species level. It refers to specialization of insects within a species. The larva, pupa or adult represent different forms in a polymorphic insect. These forms may be color polymorphism, mimetic polymorphism, wing dimorphism (alate and apterous dimorphism or macropterous and brachypterous dimorphism), sexual and parthenogenetic forms and caste polymorphism. The control factors included genetic factors, endocrinal factors, exocrinal factors and environmental factors (light quality, light intensity, photoperiod, temperature, humidity, host, nutrition and population density).

The social insects are the most prominent examples of polymorphism. They are found in Isoptera (termites), which have typical sexual reproduction, and in Hymenoptera (ants, bees and wasps), which have haplodiploid sex determination and some other insects species.

Honey bees build their nest combs on the trees. They are highly colonial, social and polymorphic insects. The honey bees have best developed social life. Mainly there are three types of individuals or castes are found in the colony of honey bees;

1. Queen is a fertile female which lays eggs. Normally one queen is found in one nest.
2. Drones are males which mate with queen. Their number in the colony is not much. Drones are produced by parthenogenesis.
3. Workers are sterile females and perform various duties of the colony. The queens and drones are fed by the workers. The worker bees are smallest members of the colony. They have chewing and lapping type of mouth parts, modified for collecting nectar and pollen of the flowers. The abdomen contains the wax glands and the sting.

Eggs of queen hatch into white, legless larvae which spin delicate silken cocoons around themselves and turn into pupae. Each pupa develops into an adult. The adult comes out by cutting wall of cocoon first and secondly by breaking the wax cap of the cell. During first 2 to 3 days, all larvae of bee are fed on a special proteinaceous food, called "Royal jelly" or bee milk which is secreted by the hypo pharyngeal glands of the young workers. After that coarser food, the "Bee Bread", which is mixture of honey and pollen grain, is given. However, the queen forming larvae are fed on royal jelly for the full larval life and these larvae are also taken for further development into a special chamber called the queen's chamber or cell.

Swarming

Swarming, is a collective behaviour exhibited by entities, particularly animals, of similar size which aggregate together, perhaps milling about the same spot or perhaps moving or migrating in some direction. As a term, swarming is applied particularly to insects, but can also be applied to any other entity or animal that exhibits swarm behaviour.

The behaviour of insects that live in colonies, such as ants, bees, wasps and termites, has always been a source of fascination for children, naturalists and artists. Individual insects seem to do their own thing without any central control, yet the colony as a whole behaves in a highly coordinated manner. Researchers have found that cooperation at the colony level is largely self-organized. The group coordination and interactions can be remarkably simple, such as one ant merely following the trail left by another insect. The organised behaviour that emerges in this way is sometimes also called as a swarm intelligence.

Swarming in honey bee

Swarming is the natural means of reproduction of honey bee colonies. In the process of swarming the original single colony reproduces to two and sometimes more colonies. Swarming is the process by which a new honey bee colony is formed when the queen bee leaves the colony with a large group of worker bees. In the prime swarm, about 60% of the worker bees leave the original hive location with the old queen. This swarm can contain thousands to tens of thousands of bees.

Swarming is mainly a spring phenomenon, usually within a two- or three-week period depending on the locale, but occasional swarms can happen throughout the producing season. Secondary afterswarms may happen but are rare. Afterswarms are usually smaller and are accompanied by one or more virgin queens. Sometimes a beehive will swarm in succession until it is almost totally depleted of workers.

For instance, one species of honey bee that participates in such swarming behavior is *Apis cerana.* The reproduction swarms of this species settle 20–30 m away from the natal nest for a few days and will then depart for a new nest site after getting information from scout bees. Scout bees search for suitable cavities in which to construct the swarm's home. Successful scouts will then come back and report the location of suitable nesting sites to the other bees.

Initially the worker bees of colony forms **queen cups** throughout the year. When the hive gets ready to swarm the queen lays eggs into the queen cups. New queens are raised and the hive may swarm as soon as the queen cells are capped and before the new virgin queens emerge from their queen cells. A laying queen is too heavy to fly long distances. Therefore, the workers will stop feeding her before the anticipated swarm date and the queen will stop laying eggs. Swarming creates an interruption in the brood cycle of the original colony.

During the swarm preparation, scout bees will simply find a nearby location for the swarm to cluster. When a honey bee swarm emerges from a hive they do not fly far at first. They may gather in a tree or on a branch only a few metres from the hive. There, they cluster about the queen and send 20 - 50 scout bees out to find suitable new nest locations. This intermediate stop is not for permanent habitation and they will normally leave within a few hours to a suitable location. It is from this temporary location that the cluster will determine the final nest site based on the level of excitement of the dances of the scout bees. It is unusual if a swarm clusters for more than three days at an intermediate stop.

Swarming creates a vulnerable time in the life of honey bees. Cast swarms are provisioned only with the nectar or honey they carry in their stomachs. A swarm will starve if it does not quickly find a home and more nectar stores. This happens most often with early swarms that are cast on a warm day that is followed by cold or rainy weather in spring. The remnant colony after having cast one or more swarms is usually well provisioned with food, but the new queen can be lost or eaten by predators during her mating flight, or poor weather can prevent her mating flight. In this case the hive has no further young brood to raise additional queens, and it will not survive. An afterswarm will usually contain a young virgin queen.

Absconding - Absconding is a process where the whole hive leaves rather than splits like in swarming. Africanized bees are notable for their propensity to swarm or abscond. Being tropical bees, they tend to swarm or abscond any time food is scarce, thus making themselves vulnerable in colder locales. Mainly for lack of sufficient winter stores, the Africanized bee colonies tend to perish in the winter in higher latitudes. Generally, a weak bee colony will not swarm until the colony has produced a larger population of bees. Weak bee colonies can be the result of low food supply, disease such as Foulbrood Disease, or from a queen that produces low quantities of eggs.

Nest site selection

The scout bees are the most experienced foragers in the cluster. An individual scout returning to the cluster promotes a location she has found. She uses a dance similar to the waggle dance to indicate direction and distance to others in the cluster. The more excited she is about her findings the more excitedly she dances. If she can convince other scouts to check out the location she found, they may take off, check out the proposed site and promote the site further upon their return. Several different sites may be promoted by different scouts at first. After several hours and sometimes days, slowly a favourite location emerges from this decision making process. In order for a decision to be made in a relatively short amount of time, a decision will often be made when somewhere around 80% of the scouts have agreed upon a single location. When that happens, the whole cluster takes off and flies to it. A swarm may fly a kilometer or more to the scouted location. This collective decision making process is remarkably successful in identifying the most suitable new nest site and keeping the swarm intact.

Locusts

Locusts are the swarming phase of the short-horned grasshoppers of the family Acrididae. Some species can breed rapidly under suitable conditions and subsequently become gregarious and migratory. They form bands as nymphs and swarms as adults both of which can travel great distances, rapidly stripping fields and greatly damaging crops. The largest swarms can cover hundreds of square miles and contain billions of locusts. A locust can eat its own weight (about 2 grams) in plants every day. That means one million locusts can eat about one ton of food each day, and the largest swarms can consume over 100,000 tonnes each day.

Swarming in locusts has been found to be associated with increased levels of serotonin which causes the locust to change colour, eat much more, become mutually attracted, and breed much more easily.

Ants swarming

Many ant species exist and as a part of their seasonal activity, ants will produce a swarm of winged flying ants, known as swarmer ants. Swarming is also known as reproductive flight, as the ants are out to start new colonies. Swarming is seasonal, often taking place in the spring, and can occur once to a few times a year. It typically lasts for one day and happens simultaneously for all colonies in an area, which increases the chance of a queen finding a mate from a different colony. Most ant species release swarmers in the late afternoon, typically after a shower of rain followed by sun.

Swarmer ants are sexually developed females and males that separate from established colonies to start new colonies. Ideally they will mate with ants from another swarm to strengthen their genetics. Mating often occurs in flight; then the female pulls her own wings off and finds a place to form a brood chamber, where she will lay eggs. Most will not succeed in successfully establishing a new colony, instead getting eaten by predators or dying of starvation.

13.8 Summary

Insects are the dominant group of organisms on earth, in terms of both taxonomic diversity and ecological function. Insects play significant roles in the ecology of the world due to their vast diversity of form, function and life-style; their considerable biomass; and their interaction with plant life, other organisms and the environment. Insects form an important part of the food chain.

13.9 Self Assessment Questions

1. Describe the role of various abiotic factors in insect life.
2. Describe the interspecific interactions in insects.
3. What do you mean by Vital Temperature? How it effects on insect life?
4. Explain the details of intraspecific interactions of insects
5. Explain the acclimation in insects.
6. Describe the different factors influenced by moisture in insect life?
7. Write an essay on biotic factors in insect ecosystem
8. Write a short note on effect of light on an insect.
9. Describe the parental care in different insects?
10. Explain the different stages of diapause.
11. Explain Cooperation, aggregation, colonial and social life
12. Explain in brief the Predators-prey interaction
13. Give examples of various predators of insects.

14. Write an essay on population dynamics of insects.
15. Describe the various methods used for sampling
16. What are the different causes of population fluctuations?
17. Write a short note on host plant insect interactions
18. Explain the various biochemical adaptations of insects against environmental stress.

13.10 Reference Books

- Elements of Entomology- Dr. Rajendra Singh
- A Text Book of General Entomology - M.S. Mani
- A Text Book of Applied Entomology (Vol.II) - K.P. Shrivastava,
- Introduction to General and Applied Entomology - V. B. Awasthi
- Biology of Insects – S.C. Saxena

Unit - 14

Insect Ecology-II

Structure of the Unit

14.1 Objectives

After going through this unit you will be able to understand

- How Insects distributed in different Biogeographical regions.
- Basic factors governing the interspecific interactions.
- Role of Mimicry
- Role of Couloration

14.2 Introduction

Insects are the Animals who are successfully dominating the Animal Kingdom on the basis of their largest number. Their distribution in different Biogeographical area is important to know their diversity. Many adaptive featureless like Mimicry and Coulration are important one in the Insects. This chapter will help to understand above phenomenon.

14.3 Biogeographical Regions of India

India can be divided into ten major regions, based on the geography, climate, pattern of vegetation seen and the communities of mammals, birds, reptiles, amphibia, insects and other invertebrates that live in them. Each of these regions contains a variety of ecosystems such as forests, grasslands, lakes, rivers, wetlands, mountains and hills, which have specific plant and animal species. Insects are Important fauna resides in the all regions of India.

14.3.1 India's Biogeographical Zones

Our Country is mainly divided into 10 Biogeographical Zones as -

1. The cold mountainous snow covered Trans Himalayan region of Ladakh.
2. The Himalayan ranges and valleys of Kashmir,Himachal Pradesh, Uttarakhand, Assam and other North Eastern States.
3. The Terai, the lowland where the Himalayan rivers flow into the plains.
4. The Gangetic and Bhramaputra plains.
5. The Thar Desert of Rajasthan.
6. The semi arid grassland region of the Deccan plateau Gujarat, Maharashtra, Andra Pradesh, Karnataka and Tamil Nadu.
7. The Northeast States of India,
8. The Western Ghats in Maharashtra, Karnataka and Kerala.
9. The Andaman and Nicobar Islands.
10. The long western and eastern coastal belt with sandy beaches, forests and mangroves.

14.4 Insect Biodiversity

14.4.1 Role of Biodiversity

Diversity of species as well as of ecosystems is essential at global, regional and local levels. As production of oxygen, reducing carbondioxide, maintaining the water cycle, protecting soil are important services provided by the both. The world community now acknowledges that the loss of biodiversity contributes to global climatic changes. Forests are the main resourses for the conversion of carbon dioxide into carbon and oxygen. The loss of forest cover along with the increasing release of carbon dioxide and other gases through industrialization contributes to the 'greenhouse effect'. Global warming is melting ice caps, resulting in a rise in the sea level which will submerge the low lying areas in the world. This is causing major atmospheric changes, leading to increased temperatures, serious droughts in some areas and unexpected floods.

Biological diversity of insects plays an important role in preserving ecological processes, such as fixing and recycling of nutrients, soil formation, circulation and cleansing of air and water, global life support, maintain the Environment.

14.4.2 Indian Insect Biodiversity

The Indian region is recognized as one of the major centres of biodiversity in the world. The diversity of country is equally rich at the ecosystem level and at the species level has been well documented by field work carried out by experts and professional field biologists. The habitat diversity offered by alpine ecosystem to mangrove ecosystem through a wide range of tropical forest ecosystem, freshwater and marine ecosystem, desert and island ecosystem found expression in richness of faunal elements in all groups. Today India, occupying 2 percent of global space (Ghosh, A.K. 1990, 1994), documents nearly 7 percent of global faunal diversity. In Phylum Arthropoda, India has 6.13 percent of total species recorded so far in the world (60,383 species out of 98, 3744 (ZSI, 1991; Gosh A.K. 1996). The total numbers of Insect Species are highest with compare to other Animal Taxa all over world. An estimate of the numbers of species by group in India is given below. This is based on Alfred, 1998.

Taxonomic Group	World species	Indian species	% in India
PROTISTA			
Protozoa	31250	2577	8.24
Total (Protista)	31250	2577	8.24
ANIMALIA			
Mesozoa	71	10	14.08
Porifera	4562	486	10.65
Cnidaria	9916	842	8.49
Ctenophora	100	12	12
Platyhelminthes	17500	1622	9.27
Nemertinea	600		
Rotifera	2500	330	13.2
Gastrotricha	3000	100	3.33
Kinorhyncha	100	10	10
Nematoda	30000	2850	9.5
Nematomorpha	250		
Acanthocephala	800	229	28.62
Sipuncula	145	35	24.14
Mollusca	66535	5070	7.62
Echiura	127	43	33.86
Annelida	12700	840	6.61
Onychophora	100	1	1

Taxonomic Group	**World species**	**Indian species**	**% in India**
Arthropoda	987949	68389	6.9
Crustacea	35534	2934	8.26
Insecta	853000	53400	6.83
Arachnida	73440		7.9
Pycnogonida	600		2.67
Pauropoda	360		
Chilopoda	3000	100	3.33
Diplopoda	7500	162	2.16
Symphyla	120	4	3.33
Merostomata	4	2	50
Phoronida	11	3	27.27
Bryozoa (Ectoprocta)	4000	200	5
Endoprocta	60	10	16.66
Brachiopoda	300	3	1
Pogonophora	80		
Praipulida	8		
Pentastomida	70		
Chaetognatha	111	30	27.02
Tardigrada	514	30	5.83
Echinodermata	6223	765	12.29
Hemichordata	120	12	10

Taxonomic Group	World species	Indian species	% in India
Chordata	48451	4952	10.22
Protochordata (Cephalochordata+Urochordata)	2106	119	5.65
Pisces	21723	2546	11.72
Amphibia	7533	350	4.63
Reptilia	5817	456	7.84
Aves	9026	1232	13.66
Mammalia	4629	390	8.42
Total (Animalia)	1196903	868741	7.25
Grand Total (Protosticta+Animalia)	1228153	871318	7.09

As you have already studied that Class Insecta is most diverse class among Animals and also you have already studied about different species found in class Insecta. For easy understanding, we are discussing here only order Orthoptera where 1033 species and subspecies belonging to 398 genera and 21 families to this order from India. The order Orthoptera is further divided into two suborders namely Caelifera and Ensifera. The forst suborder Caelifera includes short-horned grasshoppers, locusts and grouse locusts; similarly suborder Ensifera includes long-horned grasshoppers, katydids, crickets and mole crickets.

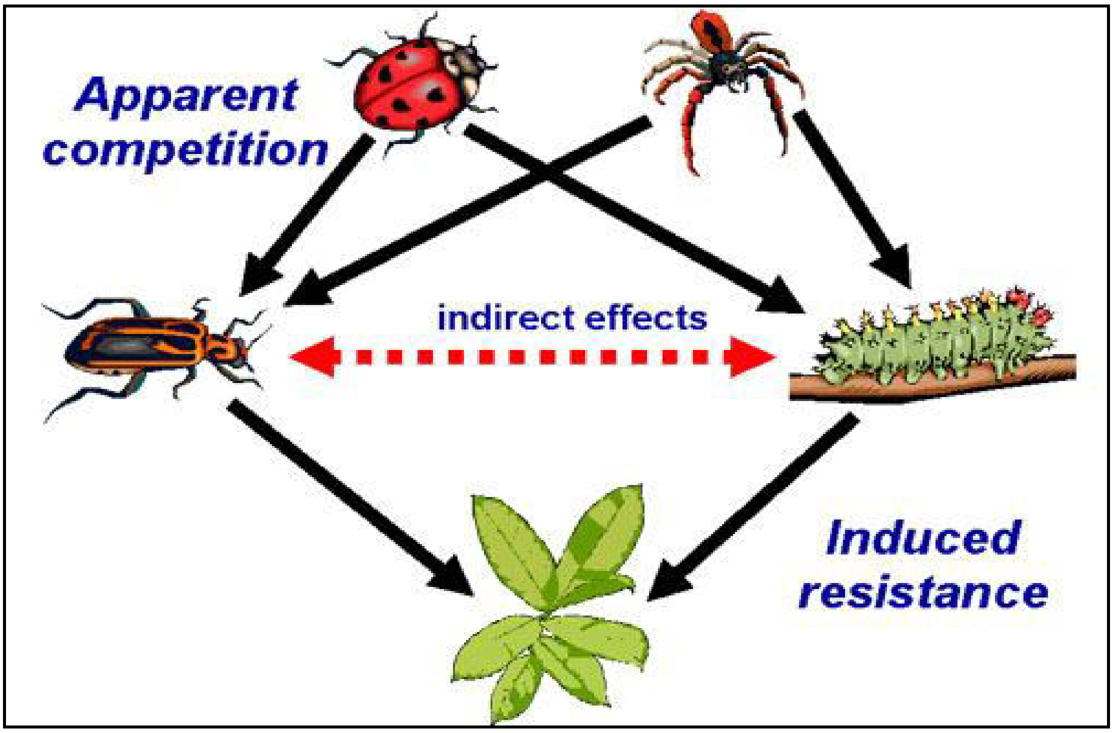
The suborder Caelifera is having 518 species under 214 genera and 11families viz. Acrididae (285 species and 134 genera), Dericorythidae (04 species and 02 genera), Pamphagidae (01 species and 01 genus), Chorotypidae (09 species and 07 genera), Eumastacidae (08 species and 04 genera), Mastacideidae (08 species and 02 genera), Pyrgomorphidae (47 species and 21 genera), Tetrigidae (137 species and 39 genera), Tridactylidae (19 species 04 genera).

The suborder Ensifera is represented by 515 species, 184 genera and 10 families namely Gryllidae (231 species and 72 genera), Trigonidiidae (22 species and 08 genera), Gryllotalpidae (08 species and 02 genera), Mogoplistidae (14 species and 07 genera), Myrmecophilidae (04 species and 01 genera), Prophalangopsidae (01 species and 01 genus), Rhaphidophoridae (14 species and 04 genera), Schizodactylidae (03 species and 01 genus), Anostostomatidae (06 species 05 genera), Gryllacrididae (49 species and 14 genera), Stenopelmatidae (03 species and 01 genus) and Tettigoniidae (160 species and 68 Genera; Kailash Chandra et.al. ZSI Jabalpur).

14.5 Interspecific Interactions and Their Types (Classification)

Ecology is a branch of science that deals with the study of distribution as well as abundance of organisms in the ecosystem, and their interactions with the environments. The environment includes two factors 1. Abiotic and 2. Biotic. You know that all living things in an ecosystem are interdependent, the associations existing between the different organisms in the ecosystem influences the survival of organisms and the functioning of the ecosystem as a whole. To understand the overall dynamics of the ecosystem, it is important to consider the impact of both environmental factors and multispecies interactions, which will have both ecological and evolutionary effects as well. It has been observed that some of the ecological interactions are mutually beneficial, or mutually detrimental or neutral.

Biological interactions are the effects that the organisms in a community have on one another in a particular area. In the natural environment no organism exists in absolute isolation. Every organism interacts with the environment and other organisms. Interactions of an organism with its environment are fundamental to the survival of that organism and the functioning of the ecosystem as a whole. Not only animals do interact with each other whereas plants do also interact during interspecific interactions. The black walnut secretes a chemical from its roots that harms neighboring plants, an example of Antagonism. There is mutualism interaction between the red-billed oxpecker and the giraffe. In Environment, Biological interactions can involve individuals of the same species-Intraspecific interactions or individuals of different species -Intersecific interactions. Both can be further classified by either the mechanism of the interaction or the strength, duration and direction of their effects. Species may interact once in a generation as during Pollination or live completely within another as during Endosymbiosis. Effects range from consumption of another individual as during predation, herbivory, or cannibalism, to mutual benefit as observed during mutualism. Interactions need not be direct; individuals may affect each other indirectly through intermediaries such as shared resources or common enemies in ecology.



(Source : https://www.entm.purdue.edu/ecolab/competition.php)

14.6 Lotka-Volterra Model of Competition

14.6.1 Introduction

Interspecific competition refers to the competition between two or more species for some limiting resource in a given area. This limiting resource may be food or nutrients, space, mates, nesting sites or anything for which demand is greater than supply in the area. When a perticular species is a better competitor, interspecific competition negatively influences the other species by reducing population sizes and/or growth rates, which in turn affects the population dynamics of the competitor in the area. The Lotka-Volterra model of interspecific competition is a simple mathematical model used to understand how different factors affect the outcomes of competitive interactions in an area.

This was proposed in 1925 by the American biophysicist Alfred Lotka and the Italian mathematician Vito Volterra.

14.6.2 Importance

Competitive interactions between organisms have a good deal of influence on species evolution, the structuring of communities, and the distributions of species. Modeling these interactions provides a useful framework for predicting outcomes of competition among species.

Species do not exist in isolation of one another in an area. The simple models of exponential and logistic growth fail to capture the fact that species can-

- Compete for resources in an area
- Assist one another
- Exclude one another
- Kill one another

Here we will generalize the logistic model to take into account resource competition between two species in an area.

Model Parameters

Let us use $N_{1,}$ $N_{2,}$ $r_{1,}$ $r_{2,}$ K_1 and K_2

N_1 = No. of individuals of species 1

N_2 = No. of individuals of species 2

r_1 = Intrinsic growth rate of species 1

r_2 = Intrinsic growth rate of species 2

K_1 = Carrying capacity of species 1 when species 2 is absent

K_2 = Carrying capacity of species 2 when species 1 is absent

The assumption underlying the Lotka-Volterra competition equations is that competing species use of some of the resources available to a species in an area (as if there were actually more individuals of the latter species):-

No. of individuals using resources of species 1 = $N_1 + \alpha_{12} N_2$

α_{12} is called the Competition Coefficient measuring the effect of an individual of species 2 on an individual of species 1. Similarly,

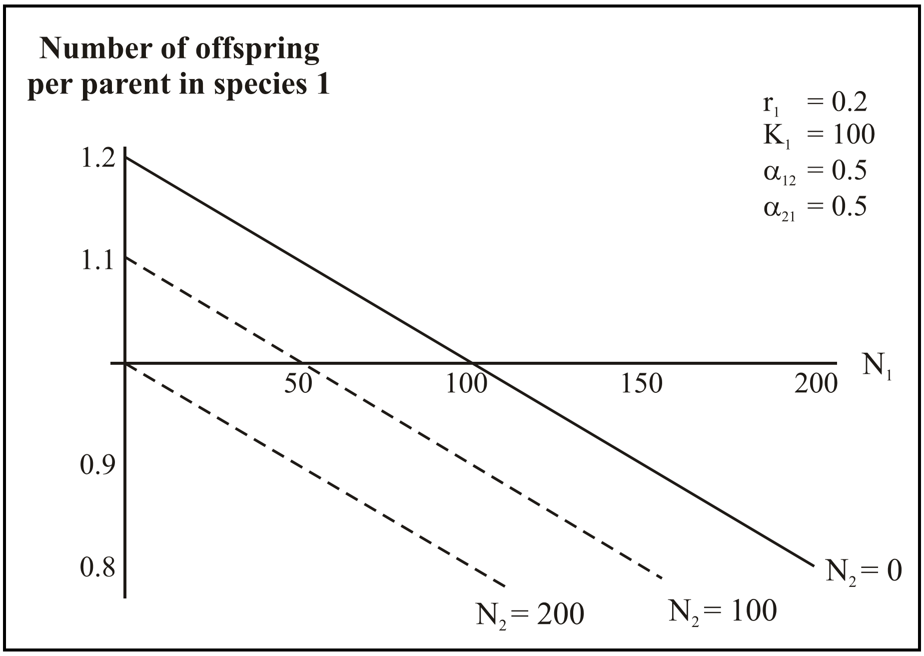
No. of individuals using resources of species 2 = $N_2 + \alpha_{21} N_1$

Discrete Model

The assumption of the logistic model is that the number of offspring per parent decreases linearly with the number of individuals (of species 1) currently in the population in an area.

With a second competing species also present, the number of offspring per parent depends not only on N_1, but also on the value of N_2:

No. of offspring per parent in species 1= $1 + r_1 \left(1 - \frac{N_1 + \alpha_{12} N_2}{K_1}\right)$



Therefore the population size in the next generation will equal:

$$N_1[t+1] = N_1[t] \left(1 + r_1 \left(1 - \frac{N_1[t] + \alpha_{12} N_2[t]}{K_1}\right)\right)$$

Similarly,

$$N_2[t+1] = N_2[t]\left(1 + r_2\left(1 - \frac{N_2[t] + \alpha_{21} N_1[t]}{K_2}\right)\right)$$

Continuous Model

In this case, it is assumed that the individual's contribution to the population growth rate in the area is

$$r_1\left(1 - \frac{N_1 + \alpha_{12}\, N_2}{K_1}\right) \text{ for species 1}$$

$$r_2\left(1 - \frac{N_2 + \alpha_{21}\, N_1}{K_2}\right) \text{ for species 2}$$

Therefore the growth rate of the entire population is equal to:

$$\frac{dN_1}{dt} = N_1 r_1\left(1 - \frac{N_1 + \alpha_{12}\, N_2}{K_1}\right) \text{ for species 1}$$

$$\frac{dN_2}{dt} = N_2 r_2\left(1 - \frac{N_2 + \alpha_{21}\, N_1}{K_2}\right) \text{ for species 2}$$

We'll focus on the discrete case in class.

Note:

In both the discrete and continuous cases,

- If α_{12} equals zero, then the dynamics of species 1 will follow the logistic equation we have analysed before.
- If α_{21} equals zero, then the dynamics of species 2 will follow the logistic equation we have analysed before.
- If α_{12} equals one, then individuals of species 2 compete for the resources of species 1 just as strongly as do members of species 1 (*interspecific* competition is as strong as *intraspecific* competition).
- If α_{12} is negative, then the presence of species 2 increases the resources available to species 1.
- If both α_{12} and α_{21} are negative, the species are said to have a *mutualistic* relationship.

- If α_{12} or α_{21} is negative and the other is zero (or very nearly zero), the species are said to have a *commensal* relationship.
- If one of the two is positive and one is negative, the species are said to have a *parasitic* relationship.
- If both are positive, the species are said to have a *competitive* relationship.
- We will also analyse the effects of competition (with $\alpha_{12} > 0$ and $\alpha_{21} > 0$) on the dynamics of two species.

Preliminary Graphical Analysis

The first step of an analysis may be to graph examples to see what happens to each of the species under different parameter conditions as:

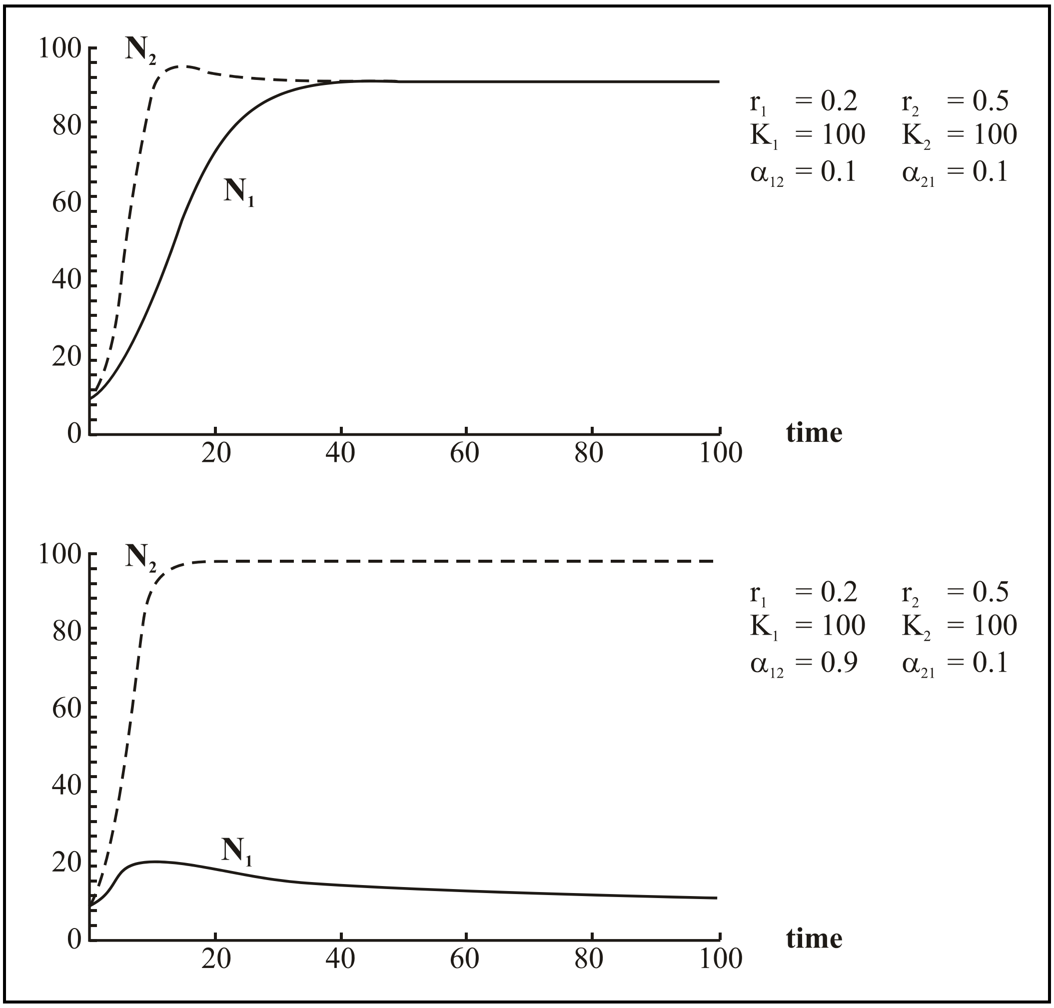
clear[pop1,pop2]

pop1[r1_,r2_,k1_,k2_,a12_,a21_,t_]:=pop1[r1,r2,k1,k2,a12,a21,t]=pop1[r1,r2,k1,k2, a12,a21,t-1]*(1+r1*(1-(pop1[r1,r2,k1,k2,a12,a21,t-1]+12*pop2[r1,r2,k1,k2,a12,a21,t]=

pop2[r1_,r2_,k1_,k2_,a12_,a21_,t_]:=pop2[r1,r2,k1,k2,a12,a21,t]=pop2[r1,r2,k1,k2, a12,a21,t-1]*(1+r2*(1-(pop2[r1,r2,k1,k2,a12,a21,t-1]+a12*pop1[r1,r2,k1,k2,a12,a21,t-1])/k2))

pop1[r1_,r2_,k1_,k2_,a12_,a21_,0]: =10

pop2[r1_,r2_,k1_,k2_,a12_,a21_,0]: =10



When α_{12} and α_{21} are small, both species approach an equilibrium level near their carrying capacities. If α_{12} is much higher than α_{21} (species 2 impacts more strongly on the resources of species 1 than vice versa), then species 1 will be kept at low numbers by the competitive superiority of species 2.

Such a graphical method is only useful for specific examples, however, does not give us a general picture of what will happen and when.

Identification of Equilibria-

As have discussed already, we determine equilibria by finding out when the variables will stay constant over time.

Unlike the case of a single variable and a single function, however, we must find an equilibrium solution where all of the variables remain constant over time.

For the continuous model of competition, this requires that $dN_1/dt = 0$ and that $dN_2/dt = 0$.

For the discrete model of competition, this requires that $N_1[t+1] = N_1[t]$ and that $N_2[t+1] = N_2[t]$.

Setting $N_1[t+1] = N_1[t] = \hat{N}_1$ in the discrete equation for species 1 gives:

$$\hat{N}_1 = \hat{N}_1 \left(1 + r_1 \left\{1 - \frac{\hat{N}_1 + \alpha_{12}\,\hat{N}_2}{K_1}\right\}\right)$$

There are two ways in which this equation can be satisfied:

$$\hat{N}_1 = 0 \qquad \text{or} \qquad \left(1 + r_1\,(1 - \frac{\hat{N}_1 + \hat{}\,\alpha_{12}\,N_2}{K_1})\right) = 1$$

↓ Rearrange

$$r_1 \left(1 - \frac{\hat{N}_1 + \alpha_{12}\,\hat{N}_2}{K_1}\right) = 0$$

↓ Rearrange

$$K_1 - \hat{N}_1 + \alpha_{12}\,\hat{N}_2 = 0$$

Setting $N_2[t+1] = N_2[t] = \hat{N}_2$ in the discrete equation for species 2 gives:

$$\hat{N}_2 = \hat{N}_2 \left(1 + r_2 \left\{1 - \frac{\hat{N}_2 + \alpha_{21}\,\hat{N}_1}{K_2}\right\}\right)$$

Again, there are two ways in which this equation can be satisfied:

$$\hat{N}_2 = 0 \qquad \text{or} \qquad \left(1 + r_2\,(1 - \frac{\hat{N}_2 + \hat{}\,\alpha_{21}\,N_1}{K_2})\right) = 1$$

↓ Rearrange

$$r_2 \left(1 - \frac{\hat{N}_2 + \alpha_{21}\,\hat{N}_1}{K_2}\right) = 0$$

↓ Rearrange

$$K_2 - \hat{N}_2 + \alpha_{21}\,\hat{N}_1 = 0$$

At equilibrium, there are four ways to ensure that both N_1 and N_2 remain constant over time:

1. both species are extinct ($\tilde{N}_1 = 0$ and $\tilde{N}_2=0$)
2. species 1 is extinct ($\tilde{N}_1 = 0$ and $\tilde{N}_2= K_2$)
3. species 2 is extinct ($\tilde{N}_1 = K_1$ and $\tilde{N}_2 = 0$)
4. both species are present.

To get both species to persist at equilibrium requires that both

$$K_1 - \tilde{N}_1 + \alpha_{12}\,\tilde{N}_2 = 0 \qquad \text{and} \qquad K_2 - \tilde{N}_2 + \alpha_{21}\,\tilde{N}_1 = 0$$

To solve both equations simultaneously:

- Solve one equation for $\tilde{N}_2$ in terms of $\tilde{N}_1$.
- Plug this value for $\tilde{N}_2$ into the other equation.
- Solve the resulting equation for $\tilde{N}_1$ in terms of the parameters of the model.
- Finally, put this equilibrium value for $\tilde{N}_1$ into one of the above equations to get an equation for $\tilde{N}_2$.

$$\tilde{N}_1 = \frac{K_1 - \alpha_{12}\,K_2}{1 - \alpha_{12}\,\alpha_{21}} \quad \text{and} \quad \tilde{N}_2 = \frac{K_2 - \alpha_{21}\,K_1}{1 - \alpha_{12}\,\alpha_{21}}$$

Only at this point will both species be present in constant numbers over time in an area. This mathematical equation is very useful to study Biological Interactions in Ecology.

14.7 Mimicry

The word mimicry has been used since 1637. It derives from the Greek term mimetikos, "imitative", in turn from mimetos. Originally it is used to describe people; "mimetic" was used in zoology from 1851, "mimicry" from 1861.

Mimicry may be of different types; it may be defensive or protective. Defensive or protective mimicry may be noticed when organisms are able to avoid harmful encounters in given time by deceiving enemies where treating them as something else.

Three types of Mimicry being discussed here to explain mimicry by the organisms protected by warning coloration:

A. Batesian mimicry - A harmless mimic poses as harmful

B. Müllerian mimicry - Two or more harmful species mutually advertise themselves as harmful

C. Mertensian mimicry - A deadly mimic resembles a less harmful but model teaches a lesson.

D. Vavilovian mimicry- weeds resemble crops, is important for several reasons, and in this case humans are the agent of selection.

Evolution of Mimicry:

It is widely accepted that mimicry evolves as a positive adaptation in Nature. The lepidopterist and novelist Vladimir Nabokov argued that although natural selection might stabilize a "mimic" form, it would not be necessary to create it in the Nature.

The widely accepted model used to explain the evolution of mimicry in butterflies is the two-step hypothesis-1. The first step involves mutation in modifier genes that regulate a complex cluster of linked genes that cause large changes in morphology. 2. The second step consists of selections on genes with smaller phenotypic effects, creating an increasingly close resemblance. This model is supported by empirical evidence that suggests that a few single point mutations cause large phenotypic effects, while numerous others produce smaller effects. Some regulatory elements collaborate to form a supergene for the development of butterfly color patterns. The model is supported by computational simulations of population genetics in nature. On other hand the Batesian mimicry in Papilio polytes is controlled by the doublesex gene.

Some mimicry is seen imperfect in nature. Natural selection drives mimicry only far enough to deceive predators in nature. For example, when predators avoid a mimic that imperfectly resembles a coral snake, the mimic is safely protected.

14.8 Aposematism Or Warning Colouration

Aposematism word derived from Greek was a new term coined by Edward Bagnall Poulton for Alfred Russel Wallace's concept of warning coloration. Warning colouration may be effective in animals; here we shall study this in detail-

The function of Aposematism is to prevent attack by the prey species, by warning the predators that the prey animal has defenses such as being unpalatable or poisonous. The easily observed warning is a primary defence mechanism, and the non-visible defences are secondary one. Aposematic signals are primarily observed visually, using bright colours and high-contrast patterns such as stripes on the body. Warning signals are clear indications of noxious prey, because conspicuousness evolves simultaneously with noxiousness. It is also observed that the brighter and more conspicuous the organism, the more toxic it usually they are.

The most common as well as effective colours are red, yellow, black and white. These colours provide strong contrast with green foliage, resist changes in shadow and lighting, have strong contrast, are highly chromatic, and provide distance dependent camouflage in nature. Some forms of warning colouration provide this distance dependent camouflage in nature by having an effective pattern and colour combination that do not allow for easy detection by a predator from a distance. Whereas warning-like from a close proximity, allowing for an advantageous balance between camouflage and aposematism. Warning colouration evolves in response to background, light conditions, and predator vision in a specific place. Sometimes visible signals may be accompanied by odours, sounds or behaviour to provide a multi-modal signal which is more effectively detected by predators.

Unpalatability by the animals can be also created in a variety of ways. Some insects such as the ladybird or tiger moth have bitter-tasting chemicals, whereas the skunk produces a noxious odour, and the poison glands of the poison dart frog, the sting of a velvet ant or neurotoxin in a black widow spider make them dangerous or painful to attack at times. Tiger moths advertise their unpalatability by either producing ultrasonic noises which warn bats to avoid them for attack, or by warning postures which expose brightly coloured body parts, or exposing eyespots as well. A wasp among ‘Velvet ants’ such as Dasymutilla occidentalis both have bright colours and produce audible noises when grabbed using stridulation, which serve to reinforce the warning.

14.9 Predator Satiation

Predator satiation; also less called predator saturation; is an antipredator adaptation in which prey occur at high population densities, reducing the probability of an individual organism being eaten. When predators have good number of potential prey, they can consume only a certain amount, so by occurring at high densities prey benefit from a safety in numbers effect. This strategy has evolved in a diverse range of prey, including notably many species of plants, insects, and fish. Predator satiation can be considered a type of refuge from predators.

It is a well established fact that if available food increases, a predator has more chances of survival, growth, and reproduction. As food supply begins more the predator's ability to consume and process it begins down.

You will see that periodical cicada (Magicicada) species erupt in large numbers from their larval stage at intervals of 13 or 17 years. In this case at high-density sites, research finds that the number eaten by birds does not increase with the number of cicada individuals as well as the risk of predation for each individual decreases.

14.10 Summary

Insects have diverse groups and distributed in many biogeographical regions. Thus insects play a major role in biodiversity. Interspecific interactions among insects and other species play a important role in environment. Lotka-Voltera Model well explains the interaction among prey and predator. Mimicry, Colouration, Predator satiation are important protective measure in Insects.

14.11 Self Learning Exercises

Section -A (Very Short Answer Type)

1. Which class (Taxon) of Animal is largest on the basis of number ?
2. Different forms of life is also known as ……………….
3. Lotka-Volterra model was proposed in the year-----------------
4. Interaction among two or more than two species is known as …………..

Section -B (Short Answer Type)

1. Define Interspecific Intraction ?
2. Write any two benefits of Interspecific Intraction.
3. Write names of any two Zoogeographical regions.
4. Name the scientist who proposed Lotka-Volterra model.

Section -C (Long Answer Type)

1. Write a note on Zoogeographical regions and Insect Biodiversity.
2. Explain Lotka-Volterra model.
3. Write Short notes on Mimicry and Warning Colouration.

Answer of Very Short Answer Questions

1. Insects

2. Biodiversity
3. 1925
4. Interspecific Intraction

14.12 References

- Alexander, Victoria N. (2002). "Nabokov, Teleology and Insect Mimicry". Nabokov Studies. 7: 177–213. doi:10.1353/nab.2010.0004.
- Begon, M., J.L. Harper and C.R. Townsend. 1996. Ecology: individuals, populations, and communities, Third Edition. Blackwell Science Ltd., Cambridge, Massachusetts, USA.
- Blount, Jonathan D.; Speed, Michael P.; Ruxton, Graeme D.; Stephens, Philip A. (2009). "Warning displays may function as honest signals of toxicity" (PDF). Proceedings of the Royal Society B (276): 871–877. doi:10.1098/rspb.2008. 1407.
- Eisner, T; Grant, RP (1981). "Toxicity, Odor Aversion, and 'Olfactory Aposematism'". Science. 213 (4506): 476. doi:10.1126/science.7244647. PMID 7244647.
- Erach Barucha, Biodiversity and its conservation in Environmental Studies for Undergraduate Course published by UGC New Delhi and Bharti Vidyapeeth Institute of Education and Research, Pune pp 286.
- Holmgren, N. M. A.; Enquist, M. (1999). "Dynamics of mimicry evolution" (PDF). Biological Journal of the Linnean Society. 66 (2): 145–158. doi:10.1111/j.1095-8312.1999.tb01880.x.
- Howse, P. E., & Allen, J. A. (1994). "Satyric Mimicry: The Evolution of Apparent Imperfection". Proceedings of The Royal Society B. 257 (1349): 111–114. doi:10.1098/rspb.1994.0102.
- Hristov, & William E. Conner. (2005).
- Hristov, N. I.; Conner, W. E. (2005). "Sound strategy: acoustic aposematism in the bat–tiger moth arms race". Naturwissenschaften. 92 (4): 164–169. doi:10.1007/ s00114-005-0611-7. PMID 15772807.
- http://www.tiem.utk.edu
- http://www.zoology.ubc.ca

- https://en.wikipedia.org
- Kailash Chandra, Sunil Kumar Gupta and M. S. Shishodia. A check list of Orthoptera (Insecta) of India; Central Zone Regional Centre, Zoological Survey of India, Jabalpur, (M.P.), India
- Karban, Richard (April 1982). "Increased Reproductive Success at High Densities and Predator Satiation For Periodical Cicadas". Ecology. 63 (2): 321–328. doi:10.2307/1938949. JSTOR 1938949.
- Kikuchi, D., & Pfenning, D. (2010). "Predator Cognition Permits Imperfect Coral Snake Mimicry". The American Naturalist. 176 (6): 830–834. doi:10.1086/657041. PMID 20950143.
- Kunte, K., Zhang, W., Tenger-Trolander, A., Palmer, D. H., Martin, A., Reed, R. D., ... & Kronforst, M. R. (2014). "Doublesex is a mimicry supergene". Nature. 507 (7491): 229–232. doi:10.1038/nature13112.
- Maan, M. E.; Cummings, M. E. (2012). "Poison frog colors are honest signals of toxicity, particularly for bird predators". American Naturalist. 179 (1): E1–E14. doi:10.1086/663197. JSTOR 663197.
- MacAuslane, Heather J. Macauslane (2008). "Aposematism". In Capinera. Encyclopedia Entomologica. 4. pp. 239–242.
- Marek, Paul. "Aposematism". Apheloria. Retrieved November 24, 2012.
- Molles, Manuel C., Jr. (2002). Ecology: Concepts and Applications (International ed.). New York: The McGraw-Hill Companies, Inc. pp. 586 pp. ISBN 0-07-112252-4.
- Pawlik, J.R. (2012). "12". In Fattorusso, E.; Gerwick, W.H.; Taglialatela-Scafati, O. Antipredatory defensive roles of natural products from marine invertebrates. Springer. pp. 677–710.
- Poulton, 1890. Foldout "The Colours of Animals Classified According to Their Uses", after page 339.
- Robertson, D. Ross (2015). "Coincidental resemblances among coral reef fishes from different oceans". Coral Reefs. 34 (3): 977–977. doi:10.1007/s00338-015-1309-8.

- Robertson, D.R. (2013). "Who resembles whom? Mimetic and coincidental look-alikes among tropical reef fishes". PLOS ONE. 8: e54939. doi:10.1371/journal. pone.0054939.

- Ruxton, G. D.; Sherratt, T. N.; Speed, M. P. (2004). Avoiding Attack: The Evolutionary Ecology of Crypsis, Warning Signals and Mimicry. Oxford University Press. ISBN 0-19-852859-0.

- Schmidt, J. O.; Blum, M. S. (1977). "Adaptations and Responses of Dasymutilla occidentalis (Hymenoptera: Mutillidae) to Predators". Entomologia Experimentalis et Applicata. 21: 99–111. doi:10.1111/j.1570-7458.1977.tb02663.x.

- Stevens, M.; Ruxton, G. D. (2012). "Linking the evolution and form of warning colouration in nature". Proceedings of the Royal Society B: Biological Sciences. 279: 417–426. doi:10.1098/rspb.2011.1932.

- Tullberg, B. S., Merilaita S., & Wiklund, C. (2005). "Aposematism and Crypsis Combined as a Result of Distance Dependence: Functional Versatility of the Colour Pattern in the Swallowtail Butterfly Larva". Proceedings: Biological Sciences. 272 (1570): 1315–1321. doi:10.1098/rspb.2005.3079.

- Wallace, Alfred Russel (1877). "The Colours of Animals and Plants. I.-- The Colours of Animals". Macmillan's Magazine. 36 (215): 384–408.

- Wang, I. J.; Shaffer, H. B. (2008). "Rapid color evolution in an aposematic species: A phylogenetic analysis of colour variation in the strikingly polymorphic strawberry poison-dart frog". Evolution. 62 (11): 2742–2759. doi:10.1111/j.1558-5646.2008.00507.x. PMID 18764916.

- Williams, Kathy S.; Smith, Kimberly G.; Stephen, Frederick M. (1993). "Emergence of 13-Yr Periodical Cicadas (Cicadidae: Magicicada): Phenology, Mortality, and Predators Satiation". Ecology. 74 (4): 1143. doi:10.2307/1940484. ISSN 0012-9658. JSTOR 1940484.

- Wilson, J., Jahner, J., Williams, K., & Forister, M. (2013). "Ecological and Evolutionary Processes Drive the Origin and Maintenance of Imperfect Mimicry". PLOS ONE. 8 (4): 1.

- "Black, White and Stinky: Explaining Coloration in Skunks and Other Boldly Colored Animals". University of Massachusetts Amberst. 27 May 2011. Retrieved 21 March 2016.
- "Periodical Cicadas, Life Cycles & Behavior". OSU. Retrieved 2015-02-06.
- A report on the five-day International Conference on Bio-Diversity of Insects: Challenging Issues in Management and Conservation conducted at Department of Zoology, Bharathiar University, Coimbatore during 30 January – 3 February 2006. Current Science, Vol. 91, No. 12, 25 December 2006, 1602-1603