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ENT-505 **Insect Ecology** **3(2-1)**

Syllabus For Mid Term Examination

Overview of Insect Ecology:

Insects are the dominant group of organisms on earth in terms of both taxonomic diversity (>50% of all described species) and ecological function (E. Wilson 1992) (Fig. 1.1). Insects represent the vast majority of species in terrestrial and freshwater ecosystems, and are important components of near-shore marine ecosystems, as well. This diversity of insect species represents an equivalent variety of adaptations to variable environmental conditions. Insects affect other species (including humans) and ecosystem parameters in a variety of ways. The capacity for rapid response to environmental change makes insects useful indicators of change, major engineers and potential regulators of ecosystem conditions, and frequent competitors with human demands for ecosystem resources or vectors of human and animal diseases.

Insects play critical roles in ecosystem function. They represent important food resources, predators, parasites or disease vectors for many other organisms, including humans, and they have the capacity to alter rates and directions of energy and matter fluxes (e.g., as herbivores, pollinators, detritivores, and predators) in ways that potentially affect global processes. In some ecosystems, insects and other arthropods represent the dominant pathways of energy and matter flow, and their biomass may exceed that of the more conspicuous vertebrates (e.g., Whitford 1986). Some species are capable of removing virtually all vegetation from a site. They affect, and are affected by, environmental issues as diverse as ecosystem health, biodiversity conservation, food production, genetically modified crops, disease epidemiology, frequency and severity of fire and other disturbances, control of invasive exotic species, land use, water and air pollution and climate change. The rapid change in frequencies of particular genes within insect populations, in response to changing environmental conditions, has provided some of the best confirmation of evolutionary principles.

Adaptation and explosive population growth in response to environmental changes, especially those resulting from anthropogenic activities, have the capacity to exacerbate or mitigate changes in ecosystem conditions and, perhaps, global processes. On the other hand, efforts to control insects have often had unintended and/or undesirable consequences for environmental quality and ecosystem services. Clearly, understanding insect ecology is critical for the effective management of environmental integrity and ecosystem services. A primary challenge for insect ecologists is to place insect ecology in an ecosystem context, which represents insect effects on ecosystem structure and function, as well as the diversity of their adaptations and responses to changes in environmental conditions. Until relatively recently, insect ecologists have focused on the evolutionary significance of life history strategies and interactions with other species, especially as pollinators, herbivores and predators (Price 1997). This focus has yielded much valuable information about the ecology of individual species and species associations, demonstrated the function of particular genes, and provided the basis for pest management or recovery of threatened and endangered species. However, relatively little attention has been given to the important role of insects as ecosystem engineers, other than to their apparently negative effects on vegetation (especially commercial crop) or animal (especially human and livestock) dynamics.

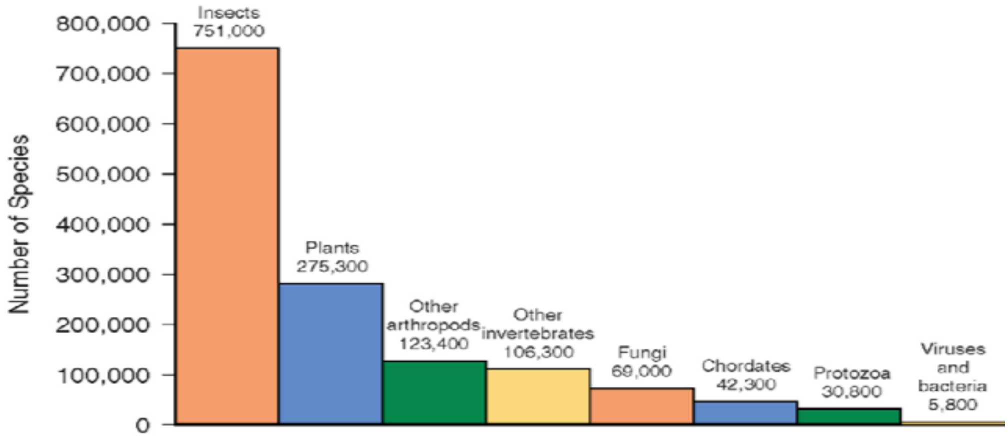


Fig I. Distribution of described species within major taxonomic groups. Species numbers for insects, bacteria and fungi likely will increase greatly as these groups become better known. Data from E. Wilson (1992).

A primary challenge for insect ecologists is to place insect ecology in an ecosystem context, which represents insect effects on ecosystem structure and function, as well as the diversity of their adaptations and responses to changes in environmental conditions. Until relatively recently, insect ecologists have focused on the evolutionary significance of life history strategies and interactions with other species, especially as pollinators, herbivores and predators (Price 1997). This focus has yielded much valuable information about the ecology of individual species and species associations, demonstrated the function of particular genes, and provided the basis for pest management or recovery of threatened and endangered species. However, relatively little attention has been given to the important role of insects as ecosystem engineers, other than to their apparently negative effects on vegetation (especially commercial crop) or animal (especially human and livestock) dynamics.

Scope of Insect ecology

Insect ecology is the study of interactions between insects and their environment. Ecology is necessarily a multidisciplinary and integrative field of study, requiring the contribu-tions of biologists, chemists, geologists, climatologists, hydrologists, soil scientists, geog-raphers, mathematicians, and others, to fully understand the complex interactions among organisms and their environment (Fig. 1.2). Some of the most exciting recent advances in insect ecology have 1) demonstrated molecular mechanisms that control biochemical interactions among organisms and the selection of genomes best adapted to prevailing conditions and 2) clarified feedback mechanisms that control insect effects on (as well as responses to) environmental changes. Despite their small size, insects have demonstrated a remarkable capacity to regulate ecosystem processes that control local-to-global envi-ronmental conditions.

Insect ecology has both basic and applied goals. The basic goals are to improve our un-derstanding and ability to model interactions and feedbacks, in order to predict changes in ecosystem and global conditions (e.g., Price 1997). The applied goals are to evaluate and manage the extent to which insect responses to environmental changes, including those resulting from anthropogenic activities, mitigate or exacerbate ecosystem change (e.g., Croft and Gutierrez 1991, Kogan 1998), especially in managed ecosystems. Some of the earliest and most valuable data on insect ecology has been contributed from studies designed to address factors affecting the population growth of “pests” (e.g., C. Riley 1878, 1880, 1883, 1885, 1893)

Research on insects and associated arthropods (e.g., spiders, mites, centipedes, mil-lipedes, crustaceans) has been critical to development of the fundamental principles of ecology, such as evolution of social organization (Haldane 1932, W. Hamilton 1964, E. Wilson 1973), population dynamics (Coulson 1979, Morris 1969, Nicholson 1958, Varley and Gradwell 1970, Varley et al. 1973, Wellington et al. 1975), competition (Park 1948, 1954), plant–herbivore (I. Baldwin and Schultz 1983, Feeny 1969, Fraenkel 1953, Rosenthal and Janzen 1979) and predator–prey interaction (Nicholson and Bailey 1935), mutualism (Batra 1966, Bronstein 1998, Janzen 1966, Morgan 1968, Rickson 1971, 1977), island biogeography (Darlington 1943, MacArthur and Wilson 1967, Simberloff 1969, 1978), metapopulation ecology (Hanski 1989) and regulation of ecosystem processes, such as primary productivity, nutrient cycling and succession (Mattson and Addy 1975, J.C. Moore et al. 1988, Schowalter 1981, Seastedt 1984, Smalley 1960). Insects and other arthropods are small and easily manipulated subjects. Their rapid numerical responses to environmental changes facilitate statistical discrimination of responses and make them particularly useful models for experimental study.

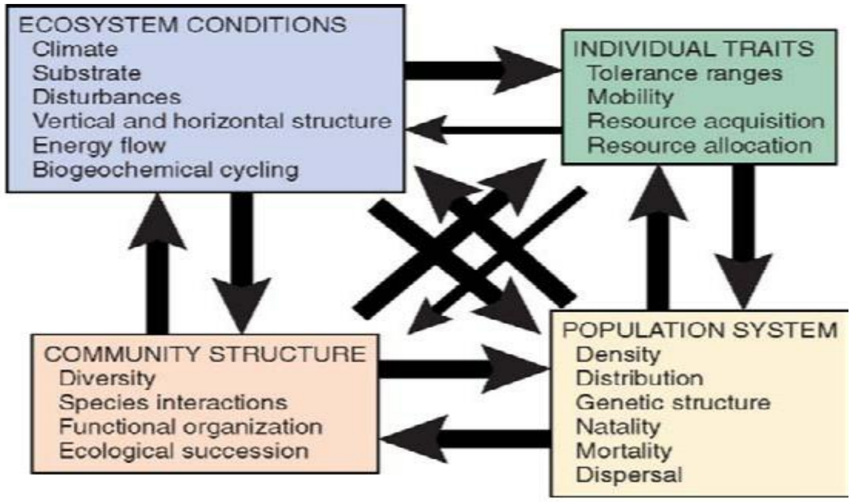


Fig. II. Diagrammatic representation of feedbacks between various levels of ecological organization. Sizes of arrows are proportional to strength of interaction. Note that individual traits have a declining direct effect on higher organizational levels, but are affected strongly by feedback from all higher levels.

Definition of Ecology & Basic Terminologies:

The word **Ecology** is the modified form of **Oekologie** derived from Greek word **Oikos**, meaning home, and logos meaning discourse/study introduced by Reiter in 1868, and later anglicized to ecology.

- **Odum** (1953) defined ecology as the study of the structure and functions of nature.
- **Ecology** is the study of the relationships between organisms and their environment.
- Insect Ecology may be defined as the understanding of physiology and behavior of insects as affected by their environment.
- The study of an individual organism or a single species is termed **autecology.**
- The study of groups of organisms is called **synecology**.
- **Ecology** can be defined as the scientific study of interactions that determine the distribution & abundance of organisms.

Distribution refers to where organisms are found. We can study distribution on different scales;

- Where found geographically
- Where found in terms of habitat
- How distributed spatially within habitat

Abundance refers to how many organisms occur. We can ask different questions about abundance;

- Does a species occur in many habitats? If so, it will appear abundant on a large scale -we will encounter it in many places.
- Are there large numbers of individuals of a species in a habitat where it occurs? If
- So, a species may be rare or abundant on a large scale, but in certain localities it will be abundant.
- We can also look at abundance in terms of numbers of species, rather than in terms of individuals of a single species. We can ask whether an area has many different species or only a few species.

Interactions refer to the relationships between an organism or species and aspects of its environment.

The above explanations of distribution, abundance, and interactions should indicate that we can study ecology on a various different levels. The main levels studied by ecologists are:

Individuals: We can consider how individuals are affected by the environment; this can determine whether they can survive (which will affect their distribution) and how well they reproduce (which will affect their abundance.)

Populations: A population is a group of organisms of the same species within a defined area. We can look at the factors that determine how large a population grows, that regulate it at a certain size, or that cause population size to fluctuate.

Communities: A community usually refers to all the organisms within an area. We can also talk about a community of some type of organism, such as the community of rodents in a paddy field in West Godavari.

Ecosystems: An ecosystem refers to all the organisms within an area and the abiotic factors that affect it. Ecosystem or ecological system is the functioning together of community and the non-living environment where continuous exchange of matter and energy takes place. In other words, ecosystem is the assemblage of elements, communities and physical environment.

Cells - Organs – Organisms – Populations – Communities.

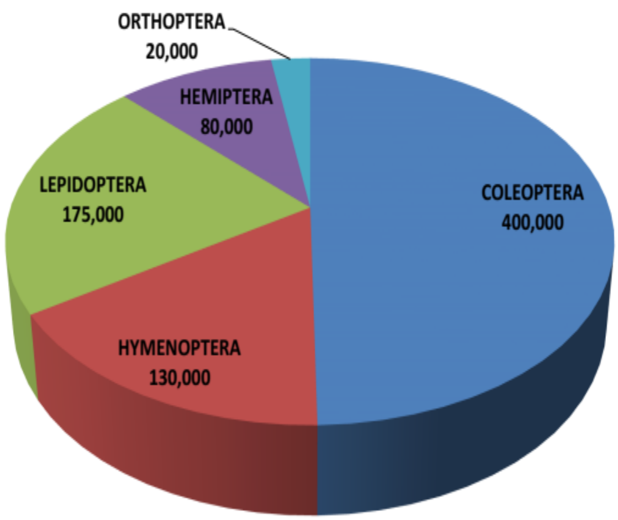
Habitat is the place where the organisms live.

The **environment** refers to the surroundings of an organism or species or sum of everything that affects the organism, and is generally considered to consist of two categories of factors: Abiotic (Density independent factors) & Biotic factors (Density dependant factors).

Why we study Insects?

- **INSECTS** are the dominant group of organisms on earth, in terms of both taxonomic diversity (***slightly over one million species of insects***) and ecological function!
- Insects play critical roles in ecosystem functions.
  - Food resources
  - Predators, parasites & disease vectors

Taxonomic richness of insects;



Basic Associations in Ecology;

Type	Interaction level	Insect example
Competition		
Intraspecific	Individuals within a population of one species	Lepidoptera larvae on trees
Interspecific	Individuals within populations of two different species	Bark beetles in tree bark
Herbivory, or phytophagy	Between autotroph and primary consumer	Aphids on roses
Symbiosis		
Mutualism	Between individuals of two species	Ants and fungi
Sociality	Between individuals of one species	Termites
Predation	Between primary and secondary consumer trophic levels	Mantids and flies
Parasitism	Between primary and secondary consumer trophic levels	Ichneumonid wasps and sawflies

Infra individual Levels of biological organization;

Organ systems-Organs-Tissues-Cells-Molecules.

Supra individual Levels of biological organization;

Organism-Population-Community-Ecosystem-Biome-Biosphere.

Biome: A group of ecosystems that have the same climate.

Biosphere: All the biomes on Earth. Thus, all the living areas of the planet.

Tundra: It is the coldest of all the biomes.

Smallest ecosystem: A drop of water from any water source is representing smallest ecosystem. The microbes in water drop interacting with each other.

Branches of Ecology;

1. **Population Ecology:** Study of group of individuals of same species in relation to their environment.
2. **Community Ecology:** Study of group of different individuals of different species in relation to their environment. You can take single environmental factor e.g. food, humidity, temperature.
3. **Ecosystem Ecology:** Study of how populations interact with their physical environment.
4. **Conservation Ecology:** Study of how to preserve and create a healthy, lasting biosphere.

Division of Ecology on the basis of Environment;

1. **Terrestrial Ecology:** The study of relationship of organisms living in terrestrial area with their environmental factors. E.g. temperature, pressure, soil, air.
2. **Aquatic Ecology:** The study of relationship of organisms living in aquatic area with their different environmental factors. E.g. water pressure, water currents.

a. Fresh water ecology: The study of living organisms living in fresh water in relation to their environmental factors of fresh water.

b. Marine water ecology: The study of relationship of organisms living in marine water with their environmental factors.

Divisions of Ecology on the basis of Subjects;

Physio-ecology: The effect of different environmental factors on the internal functions of organisms.

Morpho-ecology: The study of effect of environmental factors on the morphology of organisms.

Genetic ecology: The study of effect of environmental factors on the genetic makeup and genome of the organisms.

Insect Ecology: The study of relationship of insect to its environment.

Arthropod Ecology: The study of relationship of arthropods to their environment.

Bio Ecology: The study of relationship between life and environment.

Plant Ecology: The study of relationship of plants with its environment.

Animal Ecology: The study of relationship of animals with their environment.

Vertebrate Ecology: The study of relationship of vertebrate with its environment.

Chemical ecology: Chemicals are part of environment. They effect the life of animals. So the study of effect of chemicals on the life of animals is called chemical ecology.

The *environment* refers to the surroundings of an organism or species or sum of everything that affects the organism, and is generally considered to consist of two categories of factors: Abiotic (*Density independent factors)* & Biotic factors (*Density dependant factors)*.

- **Abiotic factors** refer to nonliving aspects of the environment that affect an organism, such as temperature, moisture and humidity, rainfall, light, atmospheric pressure, air currents, water, oxygen, pH, salinity, place to live etc.
- ***Biotic factors*** refer to other organisms that interact with an organism or species, or the organic products of those organisms. Examples of biotic factors include: the species that produce the food (*primary producers*) eaten by an organism, species that feed on and harm the organism (*consumers*), including: *predators*: species that kill and eat their prey and have no long term interaction with them, *parasites*: species that live on or in their host over a long period of time and harm, but are unlikely to directly kill, the host, *parasitoids*: species whose eggs are laid on the host (typically on the larval stages of insect hosts) and which then develop in or on the host, harming it as parasites do, but that eventually grow large and kill the host, *brood parasites*: species (typically birds) that lay eggs in the nests of their host species. The hosts care for these young and their own young are usually harmed or killed, *interspecific competitors of the organism*-other species that use the same resources and deplete supplies of those resources so that they negatively impact an organism, *mutualists*-species whose presence is helpful or essential to the organism, and who are helped by the organism, *members of same species*, through: intraspecific competition: use of same resources, so members of same species affect each other negatively, behavioral interactions.

ABIOTIC FACTORS:

- These factors are also known as *physical factors*, are *non-living* and *density independent factors.*
- Various *physical* factors of the environment have direct influence on animal distribution and abundance, and these include:

1. TEMPERATURE:

- Temperature directly influences the distribution of insects in nature, because certain amount of warmth is essential for growth and reproduction. This is the most important physical factor of the environment.
- It affects directly on the dispersal, distribution, movement, development, metabolism, fecundity and reproduction which determine the abundance of the insect and also indirectly through influence on food availability (crops) and other environmental factors such as moisture, air movement etc.
- With few exceptions, *all the developmental activities ceases at about* 0^oC, similarly beyond certain high temperatures, animals cannot live. The range of favorable temperatures for any particular species depends on the prevailing conditions under which the insect usually lives. Generally speaking, terrestrial animals have a wider range of favorable temperatures than the aquatic animals.

Based on the maintenance of body temperatures, animals are generally divided into

- ***Warm blooded*** *(Homeothermic, Endothermic)* animals maintains the body temperatures constant irrespective of atmospheric temperatures. Ex: Mammals, Birds.

- ***Cold blooded*** *(Poikilothermic, ectothermic)* animals change their body temperature when the atmospheric temperature changes. Ex: Mamals & birds
- ***Sociohomeothermic*** animals such as *honey bees* can able to maintain their body temperatures slightly above the atmospheric temperatures, and are able to air condition their nests. They maintain their own temperatures inside their colony irrespective of the temperature outside.

Temperature and Insect Development:

- In general, it is convenient to discuss the effect of temperatures in three zones *viz.*, Zone of effective temperature (temp preferend unfavourable range), Zone of inactivity and lethal / fatal zone.
- The growth of cold blooded or poikilothermic animals is arrested at 10^{o}C and this temperature is called developmental zero or threshold development.
- The optimum temperature for the normal development of insects is 10-35^{o}C and is known as Zone of Optimum or Normal Development.
- The different temperature zones from low to high are:

Zone of Fatal Low Temperature (-14^{o}C to -5^{o}C)	Zone of inactivity due to low temperature (-5^{o}C-10^{o}C)	Zone of effective temperature (10^{o}C-35^{o}C) Temperature Preferendum	Zone of inactivity due to high temperature (35^{o}C-50^{o}C)	Zone of fatal high temperature (50-60^{o}C)

-14^{o}C — -5^{o}C — 10^{o}C — 35^{o}C — 50^{o}C — 60^{o}C

Max fatal temp (-14^{o}C)	Minimum effective temp or threshold of development (10^{o}C)	Optimum temperature (10^{o}C-35^{o}C)	Maximum effective temp or threshold of development (35^{o}C)	Maximum fatal Temp (60^{o}C)

- *Zone of effective temperature (10-35^{o}C):* Active development takes place in this zone (*temperature preferendum*); at minimum effective temp or threshold of development, the development ceases and on ascending scale the development starts, while at maximum effective temperature or upper vital limit or threshold of development, the development ceases and on descending scale the development starts.

- *Zone of inactivity (-5^{o}C to 10^{o}C, and 35^{o}C to 50^{o}C):* The are the zones immediately below and above the threshold of development, and in these zones the insect will live but without development, and they can recover if removed to favorable temperatures.
- *Zone of fatal temperatures (-5^{o}C to -14^{o}C, and 50^{o}C to 60^{o}C):* The zone is fatal for insects, and cannot survive and die.
- If the insect is given a choice to move along a temperature gradient, it prefers a narrow limit of temperature known as *temperature Preferendum or preferred temperature*.
- Certain insects do not get freezes even the surrounding temperatures go below the freezing point (*cold hardiness/super cooling*). These insects have *cryoprotective compounds* like *glycerol, sorbitol and erythritol* which help insects not forming ice crystals in haemolymph by depressing the freezing point. The freezing point of most insects is between -10^{0}C to -2^{o}C. It is observed that when a cold-hardy insect is chilled the body tissue do not freeze immediately. Dehydration also enhances the cold.

Hybernation is the period of suspended activity in individuals occurring during seasonal low temperatures, while **Aestivation** is a period of suspended activity in individuals occurring during seasonal high temperatures or in dry season. This *reversible inactivity* can last for number of weeks during winter and summer, respectively. As soon as the temperature becomes moderate, these insects resume activity. It is claimed that a logistic curve completely expresses the relation between the temperature and the speed of the development. It has the form of a flattened letter "***S***" and therefore, is called a "Sigmoid Curve".

Temperature and Fecundity:

- In insects, fecundity (egg laying ability) is maximum at moderately high temperatures and decline at both upper and lower limits of favorable temperature.
- *Aphids remain parthenogenetic under high temperatures* and many hours of sunshine while the opposite condition gives rise to oviparous forms.
- If the number of days required to hatch eggs of an insect species are plotted against the temperature at which are kept, the points would fall along a symmetrical curve that resembles a hyperbola.

Temperature and Insect Distribution:

- Tropical and sub-tropical conditions like in India are favourable for distribution and establishment of insects.
- Mediterranean fruit fly *Ceratitis capitata* (Tephritidae-Diptera) could not establish in England and North Europe, because it cannot withstand temperature below 10°C.
- Mosquitoes (Culicidae-Diptera) are abundant at 70-80°F (=10°C) but are rare at 100- 113°F (30°C).
- Cotton Pink Bollworn *Pectinophora gossypiella* (Gelechidae-Lepidoptera) is serious pest and abundant in the Punjab state where temperature is 95.5°F during August-September, and is non-abundant in adjoining Western Pakistan due to high temperatures, 99°C (23°C) during August-September.

Temperature and Dispersal:

- Insects tend to move away from unfavorable temperatures.
- The rice weevil *Sitophilus oryzae* (curculionidae:coleoptera) found in the upper layers of storage bins, because the inner layers are warm and it cannot tolerate beyond 32°C and hence adults migrate to upper layers of the bins.
- Desert Locust *Schistocerga gregaria* (acrididae-orthoptera) start gathering in basking groups to gain warmth and they take flight only when the temperature near the ground is between 17-22°C and stop migrate when the temperature goes down to 14-16°C.

Adaptations to Temperatures (Acclimatization):

- The effect of temperature on growth can be quite complicated or subtle.
- In other words, the reaction to a certain changed temperature depends on whether that change has been brought gradually or suddenly. By a gradual change, the insects become conditioned and that conditioning is called acclimatization or acclimation. Based on the experiments conducted by various scientists suggests that the *rate of acclimatization is dependent on the duration for which they are conditioned*, and also depends upon whether the change in temperature is brought about suddenly or gradually.
- At high temperatures, locusts expose minimum body surface to sun rays by lying parallel to them (changes body angle) while they expose maximum body surface to sun rays at low temperatures laying at right angles to them.

2. MOISTURE

- In nature, insects are found under a wide range of moisture conditions from fresh water to the driest sun-dunes in deserts.

- For a given species, however, the range of moisture requirements is not so wide, living within that range; they maintain their body water at a fairly constant level. In aquatic animals, the dryness is expressed in terms of osmotic pressure of the water. The truly terrestrial insects can live in dry places under varying conditions of moisture. *Collembola* live in very humid places where air is always saturated with moisture. At the other extreme, the desert insects, which can survive in air containing less than 10% moisture. Since food is the source practically for all insects, their feeding habits reflects adaptations to cope with conditions of excessive moisture or shortage of water. For example, aphids and bugs, ingest large quantities of plant sap and get rid of excessive water through excretion and also special arrangement in digestive system (filter chamber). On the other hand, those living on dry foods such as grains do not get sufficient water. For example, *Ephestia* larvae could live in flour dried at 103^{o}C. This led to discovery that these insects could retain body water through metabolism.
- Of various forms of water, the vapor form plays important role in life of terrestrial organisms. A certain amount of atmospheric humidity is essential for controlling the loss of water from body. If the humidity is low, the animals die from desiccation at high temperature, and if the humidity is too high, it may harm in many ways, including the development of fungi and bacteria epizootics.
- Water is essential constituent of protoplasm, i.e. life, though the actual quantities vary in different insects. For example in *Tribolium, Sitophilus, Trogoderma and Callosobruchus*, which are pests of stored grains; water constitutes 50% of their body weight. However, bodies of most of insects contain 80-90% water and larvae of certain dipteran that live in moist surroundings contain up to 98% water. The phytophagous insects live on food that has plenty of water and it is taken up by the insect as such.

Adaptations to conserve water:

- Among terrestrial insects there are a number of other adaptations help them overcome unfavourable conditions of aridity or excessive moisture, and such adaptations may be morphological, biological and physiological.

1. Morphological adaptations:

- ***Body pigmentation*****:** In colder regions, and on the mountains, insects usually have darker body pigmentation; whereas those in deserts are generally lighter in colour. Dark colour helps to absorb the sun light which raises the body temperature, helps in removing the excessive moisture in the insect body. The lighter body colour of desert insects helps in saving the insect from moisture loss through light reflection.
- ***Integument:*** A tough integument with fused sclerites and shield like pronotum of many coleopterans helps in water / moisture conservation, since most of them live in dry habitats and feed on dry foods. Waxy coating on body of some insects also helps in water conservation.
- ***Pilocity (Hairyness):*** A dense growth of hair on the body is common in many desert insects, which saves them from excessive evaporation and also aids in reflecting the sun light.
- ***Winglessness:*** Grasshoppers and Crickets which are commonly found in arid regions and semi-deserts have generally poorly developed wings and some are wingless. For example, the Phadka Grasshopper in Western India shows variation in size of wings and the Deccan Grasshopper is wingless altogether. In the desert areas of Africa, about half of the Orthoptera found are wingless. In some species of

Tenebrionid and Carabid beetles, the wings are fused. This adaptation protects the insect against the effect of strong hot desert winds.

- ***Form of the body:*** The oval and compressed form of the body found in number of desert beetles allows the least amount of body surface being exposed to the surroundings. Moreover, they can seek shelter under stones, creeks and crevices.
- ***Other characters:*** A number of cicindelid and *carabid beetles* found in the desert have *long and slender legs*, with help of which they can walk on hot sand, without touching their bodies to sand. Other *desert insects have strong legs for burrowing in sand*, so they can burrow and bury themselves at faster rate, thus, escaping the desiccation by reducing the period of exposure.

2. Biological adaptations:

- In general, the life-cycles of insects are in tune with environmental conditions. In summer, many delicate insects *enter aestivation* or are in diapauses.
- The pupa of Red Hairy Caterpillar, *Amsacta moorei* is in diapauses during autumn and winter and even part of next summer when dry conditions prevail. With the first shower in june/july, the pupae absorb moisture which is essential for breaking diapauses, and moths emerge and lay eggs.
- Groundnut red hairy caterpillar *Amsacta albistriga* (Arctidae-Lepidoptera) enter into aestivation when dry conditions prevail.
- Similarly, there is a diapuse in summer in number of grasshoppers.

3. Physiological adaptations:

Cryptonephric condition for re-absorption of water from products of excretion so as to conserve water is present in meal worm *Tenebrio molitor* and many other coleopterans and lepidopterans.

Influence of humidity on development, fecundity etc.:

- The fall of water content of body below certain minimum proves disastrous to insects and if it is considerably above the normal (in wet places) harmful effects like viral, fungal and bacterial disease outbreaks occur.
- The phenomenon of humidity preferendum is another important factor. If the insects are given a choice to move freely in a humidity gradient with complete dryness on one end and the saturated air on the other, they have tendency to congregate within narrow range of humidity and that range is the preferred humidity. The humidity influences the rate of development, fecundity and color etc., in different insects.
- At an unfavorable humidity, the insect dies before completing its development. Even within the favourable range, all insects do not react the same way. There are three types: those in which the speed of development is retarded at high humidity (the nymphs of *Locusta* and *Schistocerca*), those have an accelerated development at high humidity (eggs of *Locusta* and *Musca*), those which have a rate of development independent to humidity (the embryonic development in the eggs of *Bruchus* not influenced by humidity). Generally, if the water content of the body is high, dry air accelerates the development.
- The adults of *Locusta migratoria* and *Schistocerca gregaria* become sexually mature quicker at a certain RH (about 70%) than in atmosphere too dry or too humid.

- The number of eggs laid by a female increases as the humidity increases upto 70% and declines again at 90%. On the other hand, fecundity of the rice weevil, *Sitophilus oryzae* increases steadily upto 70% humidity, but there is no decline in the number of eggs laid, if the humidity is increased.
- Coconut rhinoceros beetle *Oryctes rhinoceros* devlopes dark chitin in moist air and light color chitin in dry air conditions.

3. RAINFALL:

- Rainfall is closely related to humidity, and RH is dependent on rainfall.
- The total amount of RF and its distribution in time influences the abundance of insects in a tract.
- >12.5cm rain during summer (may-june) results in increase in soil moisture, which is not favourable to the cutworms, and hence are forced to come out of soil and fall a ready prey to their parasites and predators. On the other hand, if the rainfall is less than 10-12.5cm during summer, they remain protected in soil and there can be a pest outbreak in the next season. So the pest outbreak can be forecasted based on number of wet days during may-june, like if the number of wet days are <10, there will be an increase in cutworm in the following year.
- Desert locust doesn't lays eggs unless the soil has sufficient moisture, and further even if it lays eggs, the eggs will not hatch until the sufficient moisture is present in soil. Rainfall also plays an important role in movement of swarms of desert locust.
- Saturated condition of the moisture is unfavourable for the development of cotton spotted boll worm *Earias vitella*.
- Red pumpkin beetle *Rhapidopalpa foveicollis* (chrysomelidae-coleoptera) withholds eggs until it comes across moist soil.
- Rain induces emergence of most of the insects from soil, while ants, termites, red hairy caterpillar, root grub betles etc. emerge out from soil after receipt of rains.

4. **LIGHT**:

- The sun is the chief source of radiant energy and light on earth. The rays in the light spectrum play an important role in the biological field. For instance, the basic process of food manufacture in nature is accomplished under the visible rays, especially the blue and red. Wavelengths of 400-760nm are in visible range, and all the shorter wavelengths of radiant energy up to and including visible range, which is measurable is considered as an ecological factor of light.
- Different properties of light that influence the organisms are *illumination, photoperiod, wavelength of light rays, their direction and degree of polarization.* Intensity of light is measured in LUX, and luminosity is expressed quantitatively in terms on lumens.
- The effect of light on the distribution and multiplication of animals is different from the effect of temperature and moisture, in that there is no lethal effect of low or higher levels of light. There are several species of insects which can live in total darkness or continuous light. Thus, for insects, there is no medium range of favourable light comparable with temperature and moisture.
- The importance of light lies in relation to the behavior of insects and the token stimulus which it provides to enable them to regulate and synchronize their life-cycles with seasonal change. 1. ***Light & Insect movement:*** Light controls the locomotory activity of many lower organisms by direct action on their speed of locomotion. The higher activity under *increased illumination* is of great importance in the lives of many aquatic invertebrates and the smaller terrestrial forms, including insects. This undirected movement in relation to light is called *photokinesis*. 2. ***Light & Insect orientation:*** *Phototaxis**:*** Light also plays an important role in the orientation of animals through directed movements called *phototaxis*. The movement of an organism towards or away from source of light is called phototaxis. Phototaxis may be negative or positive. This behavior may serve to bring the animals to the right place at the right time. The phototactic reaction of animals to light can be modified or reversed by number of factors such as temperature, moisture, food and age. Green leaf hoppers of paddy *Nephotettix virescens* (cicadellidae:homoptera) attracts to light in hot humid conditions. Colorado potato beetles (*Leptinotarsa spp.*) are ordinarily attracted to light but are repelled when the conditions are dry. *Insects which are active during day are called as diurnal, insects which are active during night called as noctuirnal, and others which are active during dusk are known as crepuscular.*
- For example, *cockroaches* are an example of a *negatively phototactic organism,* while *moths are positively phototactic or phototactic*, meaning they automatically move toward light.
- In honeybees, there is a correlation between hours of sunshine and their activity.

- Several Moths, leafhoppers, and beetles are known to be attracted to light at dusk and during night. Chafer beetles and many moths pass the day in concealment. Most of the moths are attracted to light and are known as photopositive or phototropic. This behavior has been extensively used through light-traps for observing brood-emergence (Rice stem borer) and the population fluctuations of some insect pests. Light-traps of different colours have been tried and found that most insects attracts to UV light more than other lights. *Moths are more sensitive to some wavelengths of light-ultraviolet*, for example- than they are to others. A white light will attract more moths than a yellow light. Yellow is a wavelength moths don't respond to.
- Cockroaches hide during daytime.
- Dusk (evening light) is most usual time for flight and copulation for moths.
- Dusk is most usual time for emergence of winged white ants.
- Grubs of *Trogoderma spp. s*how -ve reaction to light (photonegative).
- Some insects are able to detect polarized light. The honeybee can perceive the degree of polarization of light in different regions of the sky and used this information in combination with other factors to determine the proper line of flight on a cloudy day
- Based on this principle, artificial light can be employed as a source for attracting of deterring insects, in IPM programs. The traps with light source for attracting various insects are known as light traps.

  3. Light & response for light hours: *Photoperiodism:* The number of hours of light in a day length of 24 hours is termed as photoperiod, and the response of organisms to the photoperiod is known as *photoperiodism.*

  Based on the response to light hours, the insects are classified in to two types; Short-day species, which likes short day lengths, and when exposed to long day lengths, they enter into inactive phase i.e. diapause (Silkworm, Bombyx mori), long-day species, likes long day hours, and when exposed to shorter day lengths, they enter into inactive phase i.e diapause (cotton pink bollworm, Pectinophora gossypiella).
- The motor activity rhythms of insects that are influenced by photoperiod include locomotion, feeding, adult emergence, mating and oviposition. The moulting and growth of some insects may be influenced by photoperiod.
- The larvae of *Plutella xylostella* (diamond backed moth) reared in laboratory with 9hrs day light (all other parameters constant) completed the development in a longer period than those exposed to 15hrs day light.

- The insect photoperiodic responses are known to control polymorphism characterized by the body form, pigmentation or the mode of reproduction. The winged and wingless forms of some aphids are produced due to the influence of photoperiod. In reduced photoperiod, sexual forms (winged forms) are produced in aphids.
- Bean weevil (*Bruchus obtectus*) lays more eggs in total darkness than in light.
- The fly of *Dacus tryoni* lays most of its eggs during the day, whereas the codling moth (*Laspeyresia pomonella*) does so during the night.
- The photoperiod plays a major role in the ecological adaptations and phonological synchronization of insects with their food sources.

4. Light & Growth, moulting and fecundity:

- Mulberry silkworm, *Bombyx mori* develops faster in light than in darkness.
- Grubs of khapra beetle, *Trgoderma granarium* develops rapidly in light than in dark.
- Moths of spotted bollworm of cotton (*Earias vitella*) and red hairy caterpillar (*Amsacta albistriga*) lay most eggs during periods of darkness.
- The bean weevil lays eggs during total darkness.
- Light stimulates the oviposition in mantids and inhibits in *Periplanata spp*.

5. Light & Body Pigmentation: In dark areas, less pigmentation develops in insects, while the light color develops in more light areas.