Profiles of insect diversity

T. N. Ananthakrishnan

Adaptability of insect behaviour to changing environmental conditions, flight aerodynamics, sequestration and detoxification mechanisms, uncanny efficiency of hormonal systems integrating behaviour, their life strategies, the aesthetic pleasure of their inimitable brilliant colouration, their object lessons in social behaviour, and their beneficial roles in pollination, biological control as well as producers of consumer products remain unsurpassed. It will be a sad reflection of the state of affairs if many species are lost for ever, particularly in the Tropical forests, thanks to human interference. This article discusses briefly the multifaceted diversity of insects with emphasis on Indian insects.

The endless limits of insect diversity

The evolutionary history of insects justifies their existence for millions of years and the passage of time has in no way diminished the wonders of insect life. Having their origin in the Carboniferous, they have shown evidence of extensive adaptive radiation in the Mesozoic, closely following the angiosperms, with further specialization in the Tertiary. Their close interactions with plants, animals and man are beyond comprehension and unquestionably they are man's closest and most relentless competitors, playing a vital role in the economy of nature. From the snow-clad heights of the Himalayas to the Tropical forests of the Western Ghats, from the deserts of Rajasthan to the rain forests of the North-East, they have exploited all kinds of environmental niches. Their numerical abundance is amazing in as much as it is inconceivable, with over an estimated ten million species with around 60,000 in this country. Many more await discovery, hopefully before many species are lost, especially in the Tropical forests, where increasing environmental depredation is rampant. Fields, forests and fresh water are not the only possible environments for insects, but also the superficial layers of the soil, where one group of primitive insects, the Collembola or spring tails, whose numbers reach from a few thousand to 700,000 cm^2 in debris rich in organic matter, play a very important role in the breakdown of organic matter in soil. The diversity of aquatic insects and their multifaceted adaptive mechanisms, as seen in dragonfly and damselfly nymphs, mayfly, stonefly and caddisfly larvae, besides whirligig beetles and mosquito larvae, are equally overwhelming. Groups of tiny flying insects constituting the aerial plankton are very common at heights up to 1500–2000 metres. Naturally, their feeding habits are diverse, involving phytophagy, carnivory, saprophagy, mycophagy, coprophagy and haematophagy. Besides, they also exploit the metabolic capabilities of micro-organisms by harbouring symbiotic bacteria in their gut, not only for cellulose digestion but also for supplementing the needed nutrients like amino acids, vitamins and sterols. Major wood feeding cerambycids like *Coelosterna scabator* (Figures 1, 2) harbour these bacteria in special diverticula of their hind gut. Insects like thrips, aphids, coccids, chalcids as well as others have the habit of initiating galls in specific plant hosts. The gall insects survive in the galls, exploiting them for nutritional purposes and for developing their progeny. The role of galls as nutritional sinks is a major feature presenting a highly evolved form of phytophagy (Figure 3).

The coevolutionary interactions of insects with plants have formed the basis for increased understanding of the diverse role of insects, resulting in competitive interactions. Such interactions involve an integration of numerous complex, chemical and nonchemical factors. The defensive strategies of plants and the evolved ability of insects to overcome plant defences have often been termed the 'evolutionary arms race'. Adaptive flexibility of insects to respond to ecological selection pressures is as important as the chemical composition of food plants. For instance, they are able to generate aerodynamic forces[1] by executing angular oscillations, helping them to be airborne, and this development of flight has enabled the insects to be out of reach of their predators and other competitors. The mass flights of locusts should inspire scientific curiosity with their stratiform and towering swarms. Equally curious is the *mass emergence* and mass migration of the red hairy

T. N. Ananthakrishnan is in the Entomology Research Institute, *Loyola College, Madras 600 034, India*

caterpillar *Amsacta albistriga* marching in millions from field to field of the groundnut crop. Seasonal, behavioural and physiological processes mediated by environmental factors govern insect–plant interactions. Their uncanny ability to choose feeding and oviposition sites naturally depend on their sensory capabilities, with information from the environment, such as colour, odour and taste, being encoded in the brain and subsequently decoded and integrated with the physiology of the insect to evoke a proper response. The focal point of such sensory capabilities lies in the antennae, the receptors on the sensillae aiding in the detection of plant odours.

Though often considered as loathesome objects in the farm and domestic fronts as agents of destruction and vectors of plant, animal and human disease, their beneficial role as producers of silk, honey, wax and lac, as pollinators (Figure 4) and as biocontrol agents has come to be admired. But what has fascinated man is their unusual array of structural and behavioural diversity, their eggs, larvae and adults, providing unusual colour combinations which are a source of considerable aesthetic beauty and are much sought after. Studying caterpillars has been described as an adventure in wonderland (Figures 5, 6). Their social organization so well demonstrated by ants, termites, bees and wasps is equally amazing offering object lessons in the successful utilization of division of labour and producing engineering marvels in their nest-building operations. No doubt, insects form an excellent material also to be used as very good models to understand their ecobehavioural aspects at all levels of their existence. It is often said that had *Drosophila* not existed, geneticists would have had to invent one, because genetics and *Drosophila* are almost synonymous.

Insects, a source of aesthetic pleasure

The diversity of insect colouration is unbelievably fantastic, ranging from metallic and iridescent colours, such as those of cantharid beetles, gourd beetles or buprestids and lycaenid butterflies, to individual or combinations of white, orange, yellow and red of pierid butterflies or ommochrome pigments typical of nymphalid butterflies (Figures 7–10). Anthocyanin pigments absorbed from plants include scarlet, purple and blue colours. The green colour of grasshoppers (Figure 11), mantids, larval caterpillars and plant bugs is produced mostly by the biliveridin pigments, which have a blue-green tint. The green is produced by an admixture of yellow, and yellow pigments are carotenoids as in stick insects or xanthophyll as in long-horned grasshoppers. Several Lepidoptera show mottled olive green markings because of the juxtaposition of melanin (black) and xanthopterin (yellow) scales vividly coloured[2]. The large saturnid moths *Antherea paphia*, *Philosamia ricini*, *Actias selene* as well as the largest of moths, *Atlas atlas* (Figure 12), are remarkable examples of such a colour pattern. The golden, green bronzy or blue metallic-coloured buprestids or jewel beetles are used in embroidery because of the splendour of their metallic lustre. The enamelled green of dragonflies is due to Tyndall blue with yellow. When carotenoids are combined with different proteins, varying colour combinations are produced. Anthocyanins have their best example in 'cochineal' from the cochineal insect, *Dactylopius tomentosus*, used to control prickly pear. The lac insect *Tachardia lacca* produces carmine.

Besides, glow worms and fireflies produce some of the most brilliant luminescence resulting in cold light or living light with the aid of light-producing organs, their continuous or flashing type of light emission being controlled by the nervous system. Light is produced when the enzyme luciferase acts on a substrate luciferin in the presence of oxygen and these beetles such as *Luciola gorhami* and *Lamprophorus tenebrosus* make use of the lights as mating signals.

Life cycle strategies and control of form and growth

Complexity and permanence of habitats, their resource diversity and availability influence the life cycle strategies of insects, irrespective of whether they are free living or parasitic, attacking plants and other vegetation, animals and man. Their endless diversity, as also that of their habitats, results in their encountering an extraordinary variety of seasonal and biotic conditions. Such factors as the length of the daytime light and darkness induce them to modify their life cycles and with such tactics as overwintering, diverse developmental rates, maternal influence and parental care they tend to overcome all the varied situations[3]. Selection of suitable feeding and oviposition sites with uncanny efficiency is typical of several phytophages like caterpillars and beetle larvae, which have the ability to sample leaves of different ages and varied nitrogen concentration as well as changing levels of plant defence compounds. Factors such as these as well as others tend to delay the duration of life cycles, which may vary from days to weeks, months and years. Cicadas, for instance, take an extremely long time of 2–17 years to complete their life cycle. Some of these are extrinsically mediated by direct effects of environment, others are endogenous mechanisms mediated by hormones.

Control of form

The rigid cuticle of insects restricts the growth of the larvae and naturally at intervals a new cuticle has to be formed and the old one cast off, a phenomenon called moulting. The brain hormone, the juvenile hormone and ecdysone are involved in moulting. Neurosecretory cells of the pars intercerebralis of the brain produce the brain hormone, which is released from the neurohaemal organ, the corpus cardiacum. The hormone stimulates the prothoracic glands and ventral glands to secrete ecdysone, which then acts on the epidermis to initiate the formation of a new cuticle. However, the type of new cuticle formed depends on the amount of juvenile hormone secreted by the corpus allatum. Larval cuticle is formed if juvenile hormone titre is high and metamorphosis occurs only when juvenile hormone titre is low, the corpus allatum inactive and ecdysone is more active. The essential feature of insect growth is therefore the existence within the epidermis of the latent capacity to develop and metamorphosis is the realization of this latent capacity for growth and reproduction. Two other hormones, the eclosion hormone and bursicon, regulate the moulting process. While the shedding of the pupal skin is triggered by the eclosion hormone, bursicon regulates hardening and darkening of the cuticle.

Morphism and functional diversity

From the dimorphism of the sexes to complicated polymorphism or existence of a species in more than one form, insects provide meaningful examples of intraspecific diversity, the most notable of which is seen in social insects. Sexual dimorphism is evident generally in larger females and smaller males, but several instances of male specialization and sex-limited polymorphism in males are equally well known. Specialization in males is exemplified in lucanids or stag beetles (*Lucanus lunifer*) (Figure 13), which have well-armed enlarged mandibles for sexual combat. In the dung beetles or heliocoprids (*Heliocopris bucephalus*) and the rhinoceros (*Oryctes rhinoceros*) (Figure 14) beetles, the enlarged horns are always outgrowths of the head and thorax[4]. Earwigs also are good examples, with males having larger and stronger and armed forceps as in *Forcipula quadrispinosa* and *Labidura riparia*. Smaller insects like the mycophagous Tubuliferan thrips show sex-limited polymorphism[5] showing an array of individuals with secondary sexual characters suppressed (gynaecoids) to those where new characters are expressed and are often bizarre (oedymeres), contributing to the heterogeneity of populations and hence enriching the gene pool. Aphids show a different type of polymorphism in which differences exist between sexual and parthenogenetic forms as well as alate and apterous types among parthenogenetic forms.

The locusts *Schistocerca gregaria* and *Locusta migratoria* provide striking examples of *phase dimorphism*, where there is a gregarious phase and a solitary phase, the former being energetic, with migratory properties and higher egg output. They show combinations of black, yellow and red colours, while the solitary phase which lack these features are greenish and more juvenile. Such group effects are equally common in Lepidoptera such as *Laphygma exigua*, which are dull green on brown when solitary, assuming a velvety black colour when reared gregariously and also acquiring a migratory tendency[6].

Seasonal dimorphism occurs in many butterflies, aphids, leafhoppers and grasshoppers, where photoperiod plays a vital role, with short days and long days influencing the growth and development of these insects. The ability of these insects to respond in diverse ways to seasonally different day lengths suggests that they have a biological clock or a time-measuring system. Photoperiod involving as it does a cycle of a period of light and darkness provides environmental information in the form of time-spaced signals, resulting in diverse activity patterns[7]. In aphids (Figures 15, 16) the viviparous parthenogenetic type of reproduction to sexual, oviparous type is brought about by the short day lengths.

It is in social insects that we come across typical examples of polymorphism involving the queen, male workers, soldiers, termites with nasute soldiers among termites. Ants, besides all these diverse forms, show functional diversity to a maximum degree with fungus growers, seed collectors, thief ants, honey ants, dairy ants and slave-making ants.

Wisdom of insect societies: their superorganism status

Insect societies, whether of ants, bees, wasps or termites, are well organized in spite of their numbers. Marching colonies of ants several metres long is a sight indeed. Sixty to eighty thousand worker bees or four to five hundred thousand ants or termites form a single colony. Termite mounds reflect master design and engineering marvels in the control of ventilation, humidity and temperature. Paper wasps use weathered wood chewed to a pulp mixed with saliva to form a durable 'paper mache'. Each insect society is regarded as a superorganism, with polymorphism and division of labour. Trophallaxis or food exchange plays a large part in their social set-up, especially of ants and termites and both have the habit of cultivating fungi in their nests. The queen termite is a phenomenal egg-laying machine (Figure 17), with its abdomen distended several hundred times the rest of the body. Behavioural changes are produced with the aid of social hormones or chemical substances which are passed on from one individual to another. The best example is the queen substance oxodecenoic acid secreted by the mandibular glands of the queen bee. Communication systems are typical of the bees, with the 'bee language' depicted by circular or figure of '8' and waggle dances translating the course to be undertaken during forage

Figure 1. Longicorn beetle larva (Cerambycid) boring the stem of *Acacia nilotica*

Figure 4. Danaid butterfly as a pollinating agent.

Figure 2. Adult longicorn beetle

Figure 5. Hairy caterpillar (*Dasychyra mendosa*) on *Acacia nilotica*.

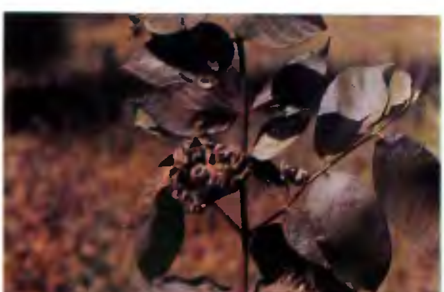

Figure 3. Thrips pouch galls of *Calycopteris floribundus*

Figure 6. Velvety caterpillar (*Achaea janata*).

7


Figure 10. Pierid and nymphalid butterflies

8


Figures 7,8. Danaid butterflies showing colour patterns

Figure 11. Grasshoppers (*Gesonula punctifrons*) on *Eichhornia*

Figure 9. Yellow Pierid butterfly

Figure 12. *Atlas* moth

Figure 13. Male stag beetle (*Lucanus lunifer*) showing enlarged mandibles.

Figure 14. Male rhinoceros beetle (*Oryctus rhinocerous*)

Figure 15. Aphids showing polymorphism.

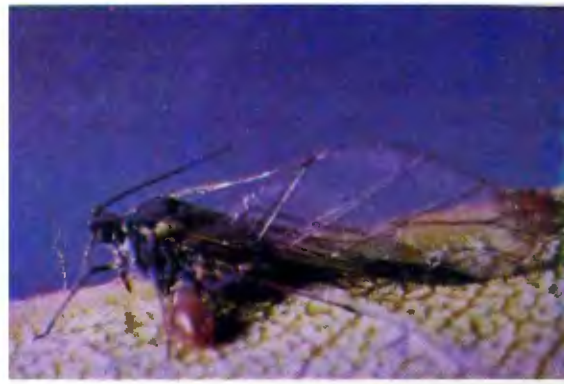

Figure 16. A typical aphid.

Figure 17. Queen termite.

Figure 18. Caterpillar of *Metanastria hyrtaca* resembling twig.

Figure 19. Pentatomid bugs aggregating in bark.

Figure 20. The painted grasshopper (*Poekilocerus pictus*).

Figure 21. Teak grasshopper nymphs (*Aularches scabiosae*) destroying teak leaf.

Figure 22. Adult teak grasshopper throwing froth

Figure 23. The hairy caterpillar *Latoia* being predated upon by a bug.

Figure 24. Predatory pentatomid bugs (*Eocanthecona furcellata*) feeding on caterpillar.

Figure 25. Predatory reduviid bug (*Rhinocoris fuscipes*) feeding on a beetle larva

Figure 27. Chalcid egg parasites.

Figure 26. Predatory reduviid bug feeding on grasshopper nymph

Figure 28. Bagworm larvae (*Pteroma plagiophleps*) in the process of being parasitized.

Bees and ants find their way home by the polarized light of the sky. The eyes of insects are sensitive to natural phenomena that man is blind to, i.e. the polarized light of the daytime sky[8]. The ability of the honey bees to navigate is also aided by the large number of visual units or ommatidia which can simultaneously scan many different parts of the celestial hemisphere.

Wasp studies have led to some of the most important discoveries in sociobiology such as nutritional control of caste and significance of dominance behaviour. Among social wasps a wide range of physical, physiological and behavioural adaptations have evolved to protect reproductive investment.

Guide to successful living: defence manoeuvres

Crypsis: Subtle mechanisms of defence, such as concealed colouration often resembling leaves and twigs or the background, are common (Figures 18, 19). Sometimes two or more unrelated species adopt similar patterns of colour so that they appear alike. Others simulate bold colour patterns of stinging insects, giving the impression of a harmful insect. By the release of toxic substances from the body, by feigning death, by adopting a threatening pose and by automatically shedding a limb or two on being caught, many insects often escape attack by predators. Insects like the preying mantis, stick and leaf insects, match their background, as also butterflies and moths and their caterpillars. Many moths imitate or mimic dead leaves by presenting a longitudinal stripe form to tip so as to look like the midrib of a leaf. Some others copy such leaf patterns as moulds or rusts or holes often seen in dead leaves. *Kallima*, the oriental butterfly, provides one of the best examples of camouflage, sitting with its wings folded besides dry leaves, looking a 100% like a dead leaf. This butterfly has vivid colours on the upper surface of wings, but the undersurface is brown and the patterns of this surface are perfectly similar to the veins in dry and dead leaves.

Sequestration of chemicals, a more potent defensive armour: Many species of phytophagous insects have developed the capacity to sequester deterrent substances of plants in an attempt to utilize them as powerful defensive armours against predators. Cyanogens, cardenolides, alkaloids are often sequestered and this exploitation of plant compounds is so remarkable a feature that such insects have provided examples of 'better living with plant chemicals'[9]. The sequestered compounds are stored in different tissues and a good example is *Poekilocerus pictus* (Figures 19, 20), the painted grasshopper abundant in calotropis plants. It sequesters the toxin calactin, calaxin and calotropin and escapes predation. Others like the teak grasshopper *Aularches miliaris* (Figures 21, 22) produce defensive secretions fortified with host plant allelochemicals. As a reaction to the presence of a predator it regurgitates or puffs out a frothy mass from the sides of the thorax. Many other grasshoppers, butterflies and moths indulge in this technique, releasing the allelochemical repellants, a phenomenon known as 'firing the allelochemical bomb'[9]. Some grasshoppers like *Zonocerus* feeding on *Crotalaria*, containing the pyrolizzidine alkaloid monocrotaline, converts it into its N-oxide before sequestration. Danaid butterflies sequester compounds stored by their immature stages and even in insect eggs allelochemicals are sequestered. They are incorporated during egg formation and smear on their surface antidietary compounds like oleic acid and alkaloids. Some larval insects eliminate ingested compounds relatively intact, like nicotine, without metabolic conversion. Major alarm pheromones are utilized by aphids to disperse their aggregation when in danger by discharging b-Farnesene from their cornicles as droplets which act as a powerful releaser of alarm pheromones[10].

Aposematic colouration: Predators learn to avoid conspicuously coloured unpalatable prey; thus, colouration acts as a warning signal. There is a coincidence between colouration and unpalatability. Aposematism is an appearance which wards off enemies because it denotes unpleasantness or danger. While predators learn aversive responses to aposematic prey, chances of sophisticated predators learning to detect deceptive prey, cannot be ruled out. In such an event of overcoming prey strategies, the only possibility for the prey to escape is through counter attack by discharging noxious chemicals causing physical damage or death. Hydrocarbons, esters, quinones are common, though others produce irritating compounds which are powerful cytotoxins like formic acid, hydrogen cyanide or salicylaldehyde[11]. The common bombardier beetle secretes two hydroquinones and hydrogen peroxide, which forms an explosive mixture aimed at adversaries.

Hairs of caterpillars such as *Euproctis*, *Latoia* (Figure 23) often contain histamine and pain-producing substances like serotonin and acetylcholine. Those of *Euproctis* adversely affect red cell structure and their venom components cause acute dermatitis. If caterpillar hairs penetrate the eyes, conjunctivitis or keratitis is caused accompanied by photophobia, increased lacrymation and oedema of eyelids. Venom glands of bees and wasps have histamines, phospholipase and hyaluronidase and also contain small proteins or peptides, such as apamin and mellitin in the bee, which exert their effect on the central nervous system. Mellitin is the main component of bee venom, having haemolytic properties, causing contraction of muscles and is a neurotoxin[12].

In some cases defence allomones contained in the haemolymph are liberated by local bleeding, with blood bubbles oozing from the joints or intersegmental membranes, when the insect is attacked. Lady birds produce coccinelline, which is distasteful. Aposematism may also include warning sounds, odours and vibration signs. Visual aposematic signals make use of emitted light as well as reflected light.

Chemical signals, the secret of behavioural diversity

Pheromones and allomones secreted by the exocrine glands into the environment act between different organisms, pheromones being intraspecific and allomones interspecific in their action. Hormones, on the other hand, produce internal signals. Pheromones attract the sexes, aid in courtship, indicate danger, act as home trails and marker territories and control many intraspecific interactions. Releaser pheromones act rapidly to produce a behavioural response. Allomones repel predation, confuse prey and are more defensive. Pheromone signals occupy space and persist for some time. Sex pheromones attract sexes over long distances and phermone detectors occur on the antennae of males. Interestingly enough, those occurring on the large, feathery antennae of insects like the silk moth *Bombyx mori* are studded with 64,000 sensory hairs of which 80% are specialists responding to sex pheromones only. Many different species of moths emit pheromones simultaneously and somehow males distinguish conspecific female scents from others. For long-range orientation, anemotaxis functions, i.e. movement based on wind direction. Evidence of electromagnetic radiation or EMR shows that during dusk, female moths become active, beat their wings continuously resulting in an increase of temperature over the ambient and at this temperature emit infrared radiation, which is picked up by male moths. In short, they operate as tiny electronic detectors of infrared; hence the concept of insect communication has come to be known as 'insect molecular bio-electronics'.

Visual clues also attract males and females in diurnal butterflies, males having a pair of large organs called hair pencils, which are tufts of fine hair-like processes. Males extrude the tuft of hair pencils from the tip of the abdomen for attraction and female lands in response. Mention may be made of pyrolizzidine alkaloids in plants, which are sequestered by the caterpillars and subsequently converted into dihydropyrolizzidine ketone which is a sex attractant. Attractants of moths are usually multicomponent blends emitted by the female and when pheromone concentration is above the threshold, males fly upwind until they come to the calling female[10]. Most attractants are aliphatic alcohols, acetates or esters. Properties of each blend differ in signal molecules, distinguishing species. Several species of Lepidoptera show 'lek formation'[13], consisting of groups of displaying males with extruded coremata attracting other males and females.

Alarm pheromones of ants, bees, wasps and termites coordinate colonial response to intruders. Ant alarm pheromone comprises hexanal and 2-butyl-2 octenal; the latter is a biting marker and 3-undecanone contributes to biting and short-range orientation signals. Territorial and trail pheromones enable efficient resource exploitation. Parasitic wasps include a territorial pheromone with each egg injected, with a host to indicate 'occupied'. Many social insects make use of recruitment trails to direct nest marks to the richest food source and they are directional. Ants and termites lay trails by dragging their abdomen along the substratum, depositing streaks of chemicals. Very few trail pheromones have been identified and are mostly terpenes, pyrazine for myrmicids and neocambrin for termites[11].

Parasitic and predatory insects: an exercise in biological control

The use of natural enemies of insect pests such as parasites and predators is the basis of biological control. Mass rearing of these parasites and predators of the specific insect pests and their release in large numbers over large areas have been successful in some cases. Today biological control is considered a part of IPM or integrated pest management, wherein timing of the release is very important as also a good knowledge of the ecology of the concerned pests. Anthocorids, some pentatomids (Figure 24), reduviids (Figures 25, 26) are well-known predatory groups, while the tiny chalcidoid parasites may be egg (Figure 27), larval and pupal parasites (Figure 28). The bitrophic interaction of parasite–host-insect or predator–prey is today replaced by the tritrophic mode of interaction in biological control involving the host plant, host insect and parasite[14]. Chemical signals from the host plant and body odours from the host insect appear very important in influencing the life activities of natural enemies. Not only the plant body odours and floral volatiles such as methyl eugenol attract pollinators, but pollen and nectar of several plants increase the life span of natural enemies. In general, compounds synthesized by plants become incorporated into the body odours of insects and this odour is used as search cue by natural enemies. For example, tricosane found in corn plants is incorporated by *Heliothis* into its egg, and *Trichogramma* uses it to find the host.

Natural enemies use a wide variety of stimuli to locate and identify their hosts based on chemical cues emanating from their bodies. Interestingly enough, even the frass of many caterpillars like *Heliothis* and *Spodoptera* contain volatiles to which larval parasites are attracted. In short, allelochemicals produced by plants that stimulate host selection behaviour of entomophagous insects form a major thrust area, wherein a parasitic species responds to its host based on the type of biochemical signal it receives from the host and accordingly the parasite searching is modified. This study is still in its infancy and needless to emphasize that an understanding of tritrophic interactions, besides being very important, could offer significant advances in future biological control programmes.

Conclusion

What has been attempted is only a fringe of the inestimable diversities of insects. The question is often posed as to the origin and evolution of these diversities. Needless to emphasize that we are yet to understand the full significance of the large amount of genetic diversity or variability in natural populations of insects which are of adaptive value. One thing that cannot be disputed is that many delicate mechanisms are involved in the life and growth of insects and in meeting the diverse vicissitudes of life to which they have shown tremendous adaptability, fully deserving to be man's closest and most relentless rivals. The emergence of biotypes in several insect species consequent to changing plant chemistry due to feeding pressure, and the increasing efficiency of insects to overcome not only plant compounds but also the battery of insecticides calls for more purpose-oriented research, to enable a better understanding of insect diversity. Notwithstanding these aspects, the increasing consciousness regarding conservation of biodiversity should provide entomologists continued opportunities to assess the changing scenario for sustaining insect diversity in natural habitats.

1. Goldsworthy, G. J. and Wheeler, C. H., *Insect Flight*, CRC Press, Florida, 1989, pp. 15–18
2. Wigglesworth, V. B., *The Life of Insects*, New York Universal Books, 1964, pp. 360.
3. Bailey, W. J. and Ridssdill, R., *Reproductive Behaviour of Insects*, Chapman and Hall, London, 1991, pp. 1–7.

4. Blum, M. S and Blum, N A, *Sexual Selection and Reproductive Competition in Insects*, Academic Press, New York, 1979, pp. 260.
5. Ananthakrishnan, T N., *Reproductive Biology of Thrips*, Indira Publishing House, Michigan, 1990, pp. 13–17.
6. Chauvin, R, *The World of an Insect*, World University Library, McGraw Hill, New York, 1967.
7. Beck, S D., *Insect Photoperiodism*, Academic Press, New York, 1980, pp 102–118.
8 Wehner, R., *Sci. Am.*, 1976, HPD, 1–11.
9 Blum, M. S., *Am. Entomol.*, 1992, **38.**
10. Lewis, T., *Insect Communication*, Academic Press, New York, 1989, pp 449
11. Evans. D. L. and Schmidt, J V., *Insect Defense*, State University of New York, 1990, pp. 289
12 Anthony, T. T., *Handbook of Natural Toxins*, Marcel Dekker, New York, 1984, vol. II, pp. 193–319.
13. Baker, T. C., *Chemical Control of Behaviour 14*, Pergamon Press, 1984, pp. 628
14. Ananthakrishnan, T N. and Senrayan, R., *Phytophaga*, 1992, 4, 87–94.

Received 20 November 1993; accepted 8 December 1993

Inter-University Consortium for Department of Atomic Energy Facilities

A. V. Pimpale and R. Srinivasan

The Inter-University Consortium for DAE Facilities was established to promote the use by university scientists of the major DAE facilities. This article summarizes the progress of various activities of IUC-DAEF in the last three years of its existence.

The Inter-University Consortium for the Department of Atomic Energy Facilities (IUC-DAEF for short) is a new concept in the academic structure of our country. Two main ideas contributed to its formation. First is the realization that research funding in Indian Universities is not keeping pace with the need for sophisticated equipment and infrastructural requirements for modern research. The ever-increasing costs of quality work make it extremely difficult for individual institutions or university departments to stake their claims for appropriate financial support. An equitable distribution of the available resources would spread it too thin for any meaningful use. The idea of multi-user institutions came to fore to address this situation and the University Grants Commission (UGC) opened the Centres like the Inter-University Centre for Astronomy and Astrophysics (IUCAA) at Pune and the Nuclear Science Centre (NSC) at Delhi. IUC-DAEF was conceived as a multi-user institution in the same spirit but with certain unique features stemming from the realization that the country has developed certain major facilities in the institutions of the Department of Atomic Energy (DAE) and a reserve of trained man-power in the universities. It was felt that making these major facilities in DAE institutions accessible to scientists from universities will be to mutual advantage. The decision to start the IUC-DAEF was thus taken after preliminary discussions between the then Chairman, Atomic Energy Commission, M. R. Srinivasan, and the Chairman of the University Grants Commission, Yash Pal. Although informal collaboration between scientists from universities and various DAE establishments had been going on for some time, the establishment of IUC-DAEF provided a formal mechanism for such co-operation between two different academic currents in the country – on the one side the research establishments of the Government of India such as DAE which have their own priorities for research and development and on the other the universities, which are autonomous institutions funded by different state governments and UGC. The memorandum of understanding signed between DAE and UGC provides for greater participation and involvement of the University system in the design, fabrication and particularly utilization of major (DAE) facilities leading to cross-fertilization of ideas, concepts, techniques and activities.

The Memorandum of Association of IUC-DAEF was formally registered on 31-7-1990. Even before it formally came into existence, IUC started functioning under the leadership of V. G. Bhide with co-operation of the Devi Ahilya Vishwa Vidyalaya, Indore, and its former Vice-chancellor, M. S. Sodha. Indore was chosen for the headquarters of IUC-DAEF since one of the major DAE facilities – an upcoming 450 MeV electron storage ring to be used as a dedicated synchrotron radiation source in the soft X-ray and VUV region of the electromagnetic spectrum – is being established at the Centre for Advanced Technology (CAT) at Indore.

Initially three major DAE facilities were specifically opened for utilization by the university personnel under the umbrella of IUC-DAEF. These were the various

The authors are in IUC-DAEF, Khandwa Road, Indore 452 001, India