Biodiversity of Entomofauna (in Part) in Cotton Field in and Around Nanguneri Taluk, Tirunelveli District, Tamil Nadu, South India.

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CERTIFICATE

The research work embodied in the present Thesis entitled **"Biodiversity of Entomofauna (in Part) in Cotton Field in and Around Nanguneri Taluk, Tirunelveli District, Tamil Nadu, South India."** has been carried out in the Department of Zoology, St. Xavier's College (Autonomous), Palayamkottai. The work reported herein is original and does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion or to any other scholar.

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LIST OF ABBREVIATIONS

°C	-	Degree Centigrade
Fig.	-	Figure
Min.	-	Minimum
Max.	-	Maximum
%	-	Percent
t/ha	-	Tonne per hectare
COPR	-	Centre for Overseas Pest Research
GDP	-	Gross domestic product
BMPs	-	Better Management Practices
>	-	Lesser than
mha	-	million hectares
kg/ha	-	kilogram per hectare
kg	-	kilogram
mm	-	millimeter
m	-	meter
CAIR	-	Centre for Agro-Informatics Research
IPM	-	Integrated Pest Management
sp.	-	Species
CLCuV	-	Cotton leaf curl virus
U.S.A	-	United States of America
CGA	-	Cotton Ginners Association
km^2	-	Square Kilometer
sq mi	-	Square mile
hrs	-	Hours

W	-	Wattage
cm	-	Centimeter
No.	-	Number
H’	-	The Shannon Diversity Index
R	-	Richness index
WWF	-	World Wide Fund for Nature
AARI	-	Ayub Agricultural Research Institute
ETL	-	Economic Threshold Level
MT/ha	-	Metric Tons/Hectare
TNAU	-	Tamil Nadu Agricultural University
Bt	-	*Bacillus thuringiensis*
sq cm	-	Square centimetre
&	-	and
RH	-	Relative Humidity
Feb.	-	February
Mar.	-	March
Apr.	-	April
Jun.	-	June
Jul.	-	July
Aug.	-	August
Sep.	-	September

CHAPTER 1
INTRODUCTION

Cotton is a major fibre crop of global importance and has high commercial value. It is grown commercially in the temperate and tropical regions of more than 70 countries. Specific areas of production include countries such as China, USA, India, Pakistan, Uzbeskistan, Turkey, Australia, Greece, Brazil, Egypt etc where climatic conditions suit the natural growth requirements of cotton, which includes periods of hot and dry weather and adequate moisture obtained through irrigation (MEF, 2011).

India has emerged as the second largest producer of cotton in the world and occupies the first position in terms of total area under crop production at over 9.44 million hectares. It is the prime cash crop of India, growing on large scale in Maharashtra, Karnataka, Madhya Pradesh, Punjab, Rajasthan, Haryana, Tamil Nadu and Uttar Pradesh and Andhra Pradesh. However, the productivity level is still below the world average. Efforts are in place to increase the current productivity to bring it closer to the world average. In addition to meeting the cotton consumption demands by domestic textile industry, India has surplus cotton available for exports. The productivity level of cotton in India varies from zone to zone (MEF, 2011).

Cotton covers a large area of cultivable land in India and other countries and plays a vital role in economy. It sustains the cotton textile industry which provides employment to millions of people. India ranks first in cotton acreage (12m ha) occupying about 34% of the global cotton area 135m ha (James, 2010). However, India has contributed about only 12% of the total cotton production. Cotton is not only the world's leading textile fiber but is also the largest foreign exchange earner in developing countries (Morris, 1990). Cotton is the good source of edible oil and natural fiber (Aslam *et al*. 2004). Cotton shares 7.8 percent value added in agriculture sector and in GDP 1.6 percent value added (Anonymous, 2013).

In India, there are nine major cotton growing states which fall under three zones viz. the North Zone 1.3mha area (Punjab, Haryana and Rajasthan), the Central Zone 7.26mha area (Maharashtra, Madhya Pradesh and Gujarat), and the South Zone 2.44mha area (Andhra Pradesh, Karnataka and Tamil Nadu). (MEF, 2011 and WWF, 2012).

The crop is generally grown in medium to deep black clayey soil, but is also grown in sandy and sandy loam soil through supplemental irrigation by farmers. Cotton is best grown in soils with an excellent water holding capacity. Aeration and good drainage are equally important as the crop cannot withstand excessive moisture and water logging. The major soil types suitable for cotton cultivation are alluvial, clayey and red sandy loam. Cotton is grown both under irrigated and rain fed conditions (MEF, 2011).

Being a cash crop, cotton is known for its intensive cultivation. Some production practices like wide plant to plant and row to row spacing and crop traits such as indeterminate growth habit, long duration, render the crop susceptible to a multitude of pests and diseases at all stages of growth. These factors are also responsible for high input use in terms of nutrients and crop protection chemicals. Aggressive production practices by farmers often lead to a very high input use, with little regard to matching returns. The excessive use of inputs, not only escalates the cost of cultivation but also decreases the profitability. It also results in pest resurgence, health and environmental hazards. Needless to say, excessive use of inputs is laying enormous pressure on land and water. In order to address these issues, WWF-India has developed the concept of operationalizing Better Management Practices (BMPs) for cotton cultivation. BMPs help balance inputs with increased farm yields (WWF, 2012).

Biodiversity mediated renewal processes and ecological functions are largely biological and their persistence depends upon the maintenance of species integrity and diversity in agro-ecosystem (Alteiri, 1999). Studies suggest that more diverse the agro-ecosystem and the longer this diversity remains undisturbed, the more internal links develop to promote greater insect stability. It is clear, however, that the stability of insect community depend not only its trophic diversity, but also on the actual density dependence nature of the trophic levels (Southwood and Way, 1997). Olfert *et al.* (2002) highlighted the importance of arthropods. According to them, arthropod fauna is integral during evaluation of ongoing cropping practice and helps in redesigning of farming systems in order to make it economically viable and environment sustainable. It is now established that arthropod predators suppress pest populations (Chang and Kareiva, 1999; Gurr and Wratten, 2000; Symondson *et al*., 2002).

Insects constitute a remarkably speciose group of organisms attributed mainly to their small size, which allows them to occupy niches not available to larger organisms. Estimates of global species richness of insects vary from less than five million to as many as 80 million Gullan and Cranston (2010). Insects are critical natural resources in ecosystems, particularly those of forests Raina *et al*. (2011). In addition to their role as efficient pollinators and natural/biological pest control agents, some insect species are important indicators in ecosystems management Buchs (2003).The habitat heterogeneity hypothesis simply predicts that more arthropod species will occur where different forms and species of plants provide greater structural heterogeneity in the vegetation Hart and Horwitz (1991). Thus, greater resources are available for the coexistence of more species within each trophic group (Moore and de Ruiter1997).

Arthropod diversity, which takes account of the relative abundance of species as well as their variety Magurran (1988), would express an asymptotic relationship with increasing numbers of plant species and greater structural heterogeneity in the vegetation. Habitat heterogeneity at small spatial scales can favour the number and abundance of arthropod species in grassland Dennis *et al*.,(1998).

Insects have very wide distribution. Study of insects is of utmost important now days. Insects have always been the friends of man, living in close association with this life. Insect biodiversity accounts for a large proportion of all biodiversity on the planet, with over 1,000,000 insect species described but current estimate of total insect diversity vary from 5-80 million species of insect. Beetles (coleopteran) make up 40% of described insect species, but some entomologists suggest that flies (Diptera) and Hymenoptera (wasps, bees and ants) could be as diverse or more-so. Five orders of insects stand out in their levels of species richness: Hymenoptera, Diptera, Coleoptera, Lepidoptera and Hemiptera. Insects ecology is the scientific study of how insects, individually or as a community interact with the surrounding environment or ecosystem (Schowalter 2006).

Insects are essential in the ecosystem by helping in nutrient recycling through leaf litter and wood degradation, carrion and dung disposal, and soil turnover. They play a major role in plant pollination and maintenance of plant community composition and structure via phytophagy Gullan and Cranston (2010). Their demise will therefore result in the disruption of critical ecosystem services such as pollination and source of food. There is therefore the need for the conservation and protection of these species. The increasing world population and changes in consumption patterns increased significance of agricultural intensification during the last few decades. Unless crop yield is improved and release of fertilizers and pesticides in the croplands is reduced, such intensification would augment contamination and perturbation of managed and natural ecosystems, ultimately damaging biodiversity and public health (Hughes, 2002). The crop systems, biodiversity performs a variety of ecological functions beyond the production of food, including recycling of nutrients, help regulation of microclimate and local hydrological cycles, suppression of undesirable organisms and detoxification of chemicals especially the agro-chemicals. There are evidences that species-rich ecosystems are more stable than species-poor ecosystems. If the relationship between biodiversity and stability holds, then it is in the interest of the long-term viability of a region to encourage diverse human and natural ecosystems (Minor, 2005). The restricted use of pesticides and landscape biodiversity management help to conserve the biocontrol agents in agro-ecosystems and favors the development of sustainable agriculture.

Cultivation of cotton under diversified agro climatic situations makes the crop to suffer a lot by different kinds of pests. The major reason for the low productivity in cotton is damage caused by insect pests. In India, as many as 162 species of insect-pests are known to attack cotton from sowing to maturity which cause up to 50-60 per cent loss (Agarwal *et al*., 1984). Cotton pests can be primarily divided into bollworms and sucking pests.

Cotton insect strainers, *Dysdercus cingulatus* Fabricius (Red cotton bug) and *Oxycarenus hyalinipennis* Costa, (Dusky cotton bug) were recorded as a major pest of Bt-cotton and non Bt-cotton in agricultural fields of Warangal, Andhra Pradesh, India. The percentage of infested plants ranged from 5 to 40% in Bt-cotton and 1 to 31% in non Bt-cotton (Chintha Sammaiah *et al*.,2012).

The yield loss in *Gossypium hirsutum* cotton due to sucking pests, bollworms and both has been recorded up to 8.45, 16.55 and 17.35 quintal ha-1 respectively

(Satpute *et al.,* 1988) whereas out of 14% losses in total agriculture due to insect pest of which 84% is in cotton (Oerke *et al.,* 1994). Jassid, whitefly, thrips and mites are major complication for escalating yield and productivity of the crop. Jassid is reported to cause 18.78 percent decline in cotton yield (Ali 1992). Similarly whitefly vector of Cotton leaf curl virus (CLCuV) Malik *et al.,* (1995) injure circuitously to cotton by secreting honeydew and transmitting cotton leaf curl viral diseases that caused normal yield loss in Pakistan up to 38.7% during 1993 (Khan and Khan 1995). whereas mealybug invasion resulted huge losses to cotton crop both in Pakistan and India. According to latest report (Muhammad 2007) available by the Centre for Agro-Informatics Research (CAIR) Pakistan, affirmed that the mealybug had shattered 0.2 million bales (170 kg lint per bale) and 150,000 acres (out of the 8.0 million acres) of cotton area all across Pakistan, chiefly in Punjab and Sindh provinces. According to Goswami (2007), in India due to mealybug plague nearly 2000 acres of cotton crop were ruined.

The average yield of cotton is about 570.99 kg/ha, which is low as compared to other cotton growing area of the world (Bakhsh *et al*., 2005). The low productivity of cotton is caused by many factors, but the most serious one is the intensity of insect pests attack. Among sucking insect pests, whitefly, jassid and thrips are important in Pakistan and cause significant yield reduction (Aslam *et al*., 2004; Amjad and Aheer, 2007). These are very destructive pests during seedling and vegetative phase of cotton as they suck the sap of the plant, make it weak and in case of severe infestation wilting and shedding of leaves occur (Abro *et al*., 2004). Among sucking pests, aphid (*Aphis gossypii* Glover), leafhoppers, *Amrasca biguttula biguttula* (Ishida), thrips, *Thrips tabaci* (Lind.) and whitefly, *Bemisia tabaci* (Genn.) are of major importance. These sucking pests occur at all the stages of crop growth and responsible for indirect yield losses. A reduction of 22.85 per cent in seed cotton yield due to sucking pests has been reported by Satpute *et al.,* (1990).

Luttrell (1994) emphasized that although the number of species recorded in the crop varied from region to region, 5-10 key pests caused significant crop damage. The abundance of insect pests depends on season length, rainfall, temperature, surrounding vegetation, and agronomic practices (e.g., pest management) (Pimentel and Wheeler, 1973; Wilson, 1994). Species diversity is a parameter of community structure involving species richness and their abundance for the given taxa (Wang *et al*., 2000). He also stated that the reduction in species richness was mainly caused by the loss of the rarely encountered species. The reason of the decline in species diversity is the increased dominance of one species (Price, 1984). Species diversity and complexity of association among species are essential to the stability of the community. In addition, knowledge of species diversity and insect pests abundance at various times are fundamental of pest control (Van Emden and Williams, 1974).

Farmers can make some simple changes to their crop systems to manipulate vegetational diversity, through addition of plants that provide specific functions (Landis *et al*., 2000; Gurr *et al*. 2003; Isaacs *et al*., 2009). Cotton is an important fiber crop grown mostly in northern Ghana. Its cultivation is threatened by the plethora of insect pests associated with the crop from the vegetative growth stage to the period of harvesting (Abudulai *et al*., 2007). Early season pests of cotton include jassids (Leafhoppers), *Empoasca facialis,* aphids, *Aphis gossypii,* grasshoppers, *Zonocerus variegatus*, cotton leafworm, *Spodoptera littoralis,* cotton looper, *Cosmophila flava,* and flea beetles. The mid-season insect pests of cotton are spiny bollworm, *Earias* sp., red bollworm, *Diparopsis watersi,* African bollworm, *Heliothis armigera,* and cotton leaf roller, *Sylepta derogata*. Examples of late season insect pests of cotton are pink bollworm, *Pectinophora gossypiella,* the false codling moth, *Cryptophleria leucotreta,* whiteflies, *Bemicia tabaci,* cottton stainers, *Dysdercus* sp., as well as all the bollworms listed as mid-season insect pest (Obeng-Ofori, 2007; Quaison-Sackey and Kwofie, 1978).

This crop is severely attacked by number of pests (David and AnanthaKrishnan, 2004). *Dysdercus cingulatus* (Fab) (Hemiptera: Pyrrhocoridae) is a serious pest of cotton in many parts of the world including India (David and Ananthakrishnan, 2004; Karihaloo and Kumar, 2009). *D. cingulatus* cause serious damage by feeding on developing cotton bolls and ripe cotton seeds (Freeman (1947) Ahmad and Schaefer (1987), Yasuda (1992), Kohno and Bui Thi (2004)).

The cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter) (Hemiptera: Miridae), is an important pest of cotton in Texas and Oklahoma, and occasional pest in New Mexico, Arkansas, Louisiana, and other mid-South states (Walker et al. 1970, Esquivel and Esquivel 2009). Cotton fleahopper is a small insect with piercing-sucking mouthparts which feed on early-stage cotton squares and cause shedding of affected squares resulting in potential yield loss (Reinhard 1926, Almand 1974).

Oxycarenus hyalinipennis (Hemiptera, Lygaeoidae) is a serious pest of cotton and feeds on cotton seeds. It is commonly referred to as the cotton seed bug. Slater and Baranowski (1994), Baranowski and Slater, (2005) reported it from the Turks and Caicos, Bahamas, Cayman Islands, and Hispaniola. According to Ananthakrishnan *et al*., (1982), adults and nymphs suck oil from mature seeds and fluid from leaves of young stems to obtain moisture. Smith and Brambila(2008) found high density of this bug in florida.

The predominant species of pentatomids (stink bugs) infesting cotton in the Southeast and Mid-South include the southern green stink bug, *Nezara viridula*, the green stink bug, *Acrosternum hilare*, and the brown stink bug, *Euschistus servus*. In recent years, the brown stink bug has become a more common pest than in previous reports. The brown stink bug has a wider range of native hosts than the southern green stink bug (Jones and Sullivan 1982, McPherson and McPherson 2000). The recent increase in this pest might be related to its ability to use a wide range of hosts. In western production regions, the brown stink bug has been reported to cause significant losses in Texas and Arizona. A related species, *E. conspersus*, impacts cotton in California. Stink bugs are primarily a pest during the flowering stages of cotton development, feeding on bolls.

There are several species of mirids that are important in cotton production systems including the tarnished plant bug, *Lygus lineolaris*, the western tarnished plant bug, *Lygus hesperus*, the clouded plant bug, *Neurocolpus nubilus*, and the cotton fleahopper, *Pseudatomoscelis seriatus*. Plant bugs have been perennial early-season pests in cotton, feeding habitually in plant terminals and on pre-floral buds (squares) (Tugwell *et al.,* 1976).

Stink bugs and plant bugs are common on vegetative- and reproductive-stage plants in cotton fields. Most data show no significant effects of stink bugs on plant growth and fruiting-form development until the plants begin to flower (Willrich 2004). Historically, plant bug feeding on bolls was considered to be a relatively unimportant source of yield loss (Scales and Furr 1968, Tugwell *et al*., 1976). Plant bugs preferentially feed on squares during pre-flowering and flowering stages. However, infestations during the flowering period can injure bolls, induce boll abscission and reduce cotton yields (Horn *et al*., 1999, Russell 1999). These pests pierce the boll wall with their piercing-sucking mouthparts and feed on developing seeds and surrounding tissues (Wene and Sheets 1964).

The majority of insect pests on cotton are polyphagous, for example the different bollworm species, cutworms, aphids and whiteflies. The most important lepidopteran pests of cotton are the bollworm complex that feed on the reproductive plant parts of the cotton plant (Morse *et al*., 2006). Some of the pest species of cotton in Zimbabwe are oligophagous, for example the cotton stainers and red bollworms. Cotton stainers (Hemiptera: Heteroptera) are an important group of insects that stains the fibre and cause a reduction in the quality of the cotton. Stefanie *et al*., (2008) mentioned that honeydew is excreted by the aphids and this allows sooty moulds to grow, resulting in a decrease in the quantity and quality of the produce which the aphids impact is especially important on vegetable crops such as courgette, melon, cucumber, aubergine and strawberry and on cotton, citrus and mallow.

Honeydew promotes sooty mould, which reduces potential crop yield by blocking sunlight and reducing assimilation of nutrients for plant growth. The mass cultivation of this crop made it a target for several pests especially the sap sucking insects belonging to order Homoptera, i.e. cotton aphid, *Aphis gossypii* Glov. and cotton and tomato whitefly, *Bemisia tabaci* (Gen.) which are the most serious insect pests attacking cotton plants and may cause damage and reduce its yield (Chaudhry,1976 and Matthews,1989).

Bemisia tabaci has become one of the most important sucking pest of world's industrial and food crops like cotton, sunflower, melon, tomato, brinjal etc. Heavy infestation may reduce plant vigor and growth, cause chlorosis and uneven ripening of bolls Greathead (1986). In many countries (Fryxell,1979) not only because of sucking sap of plant but also for transmitting different plant virus diseases to several vegetables and field crops (Cohen and Nitzany, 1966; Osaki and Inouye, 1981 and other weed plants (Duffus ,1987; Baldin,2012). The major reason of reduction in cotton yield and quality is the attack of about 150 different species of insect and mite pests Attique, and Rashid, 1983)].

Aphids (Hemiptera: Aphididae) are important pests of cotton (Cauquil 1988, Kerns and Gaylor 1992) and secondary outbreaks because of insecticide applications have been reported Kerns and Gaylor (1992). Aphid resistance towards insecticides such as carbamates, organophosphates and pyrethroids was observed by Kerns and Gaylor (1992). Whitefly (Hemiptera: Aleyrodidae) is another important pest of cotton1 for which pesticide resis- tance has been reported (Omer *et al.,*1992) and the role of biological control in managing these pests in an integrated pest management program is thus crucial (Kerns and Gaylor 1992, Kerns and Gaylor 1993). Chrysopid larvae (Neuroptera: Chrysopidae) as well as predatory ladybird larvae and adults (Coleo- ptera: Coccinellidae) are of economic importance in agriculture and have been successfully used in biological control programmes (Fürsch 1998, Picker *et al*., 2003).

Host plant selection is particularly great important among insect pests such as aphids and whitefly especially for adult females which are responsible for choosing hosts for oviposition that would be the same for feeding and are preferable for optimal survival of offspring (Futuyama 1983, Rausher 1983, Thompson 1988, Navon *et al*.,1991).

A variety of insects can cause damage to cotton, both quantitative and qualitative. Various lepidopteran species have been recorded as either major or sporadic/minor pests of cotton in Zimbabwe such as, excluding the cotton bollworm complex, cutworms (*Agrotis spp*), false pink bollworm (*Sathrobota simplex*), cotton leaf worm (*Spodoptera littoralis*), cotton semi-loopers (*Anomis flava, Xanthodes graellsi, Chrysodeixis spp* and *Trichoplusia spp*) (CGA, 1998). Several other pest are listed as sucking pests and these include aphids (*Aphis gossypyii*), whiteflies, jassids, cotton stainers, red spider mites, lygus, thrips and stink bugs. Soil pests include termites, false wireworm and nematodes which destroy root system.

The bollworms complex in cotton In Zimbabwe the bollworm complex consists of five species namely the Red bollworm (*Diparopsiscastanea*) (Hampson) (Lepidoptera: Noctuidae) African bollworm (*Helicoverpa armigera*) (Hübner) (Lepidoptera: Noctuidae), two Spiny bollworms species (*Earias biplaga* Wlk. and *E. insulana* Boisd.)(Lepidoptera: Noctuidae) and Pink bollworm (*Pectinophora gossypiella* Saunders) (Lepidoptera: Noctuidae) (CGA, 1998).

The red and African bollworms are the key bollworm pests and can cause yield losses of up to 60 % (Matthews and Tunstall, 1994). Pink bollworm is one of the most destructive pests of cotton in many areas of the world, including in India, China, Brazil and the western USA. In Zimbabwe it is potentially a serious pest which is under check by regular destruction of crop residues. Spiny bollworm damages all stages of the plant. It can appear especially serious in the first 20-30 days because the young plant has only one to several terminals - which are killed. Throughout its range these species are sporadic in terms of their appearance in one place and not another, and on one season but not the next - even within a season (Vannila *et al*., 2007).

The cotton plant is the main host for the larvae and it attacks all developmental stages of the cotton fruit (boll). Red bollworm causes damage to buds, flowers, tip and bolls. The cotton boll is normally completely destroyed. Though limited host range, the Red bollworm is oligophagous (almost monophagous) and it’s mainly found on, cultivated and wild *Gossypium* species and a related Malvaceous host, *Cienfugosia hildebrandti* (Taylor, 2015). Poor control of this pest at the end of the season will generally lead to heavier attacks in the following season. Early planted cotton will generally suffer an early red bollworm invasion which can be avoided by planting later

(CGA, 1998). However, considering the changes happening to the climate which might have resulted in a shift of planting dates forward, research has to be done to determine the effect of planting dates on cotton pests.

Direct damage to cotton is caused by larvae which feed on various parts of the crop. *H. armigera* is known to destroy leaves, buds, flowers and bolls (Rahman, 2012). Only the largest larvae will be found attacking fully developed bolls. Extensive damage to young fruiting bodies can occur rapidly during peak infestation. A damaged boll may show a distinct circular opening and be only half eaten. The larvae can cause considerable flower and boll loss due to its activities. Two to three larvae on a plant can destroy all the bolls within 15 days (Plantwise Knowledge Bank, 2012) in total in Zimbabwe can cause 1175kg/ha (Gledhill, 1976).

Cotton fields are one of the agroecosystems with interesting biodiversity (Alabama Cooperative Extension Service, 1999). Several insect pests, especially in orders Hemiptera, Coleoptera and Lepidoptera damage different parts of cotton plant all through the crop season and cause crop loss (Williams *et al*., 2000). There are diverse natural enemies (predators and parasitoids) in cotton fields which decrease the pests' population density and crop loss (Ghahari *et al*., 2008). One of these groups of beneficial insects which have efficient role in pest control in cotton fields all over the world, are lady beetles (Coleoptera: Coccinellidae) (Obrycki and Kring 1998, Ghahari and Ostovan 2006).

Predators are essential biological control agents (Sathe and Bhosle 2001). Coccinellid predators (*C. septempunctata* and *M. sexmaculata*) are the important natural enemies of aphid and keep the aphid population below the economic threshold level (Wells *et al.,* 2001). *Geocorus* spp. and *C. carnea* are voracious feeders of cotton soft bodied insect pests (Mari *et al.,* 2007).

Chrysopid larvae and some lacewings are predators and feed on aphids (Cauquil 1988, Mansell 1998, Picker *et al*., 2003, Michel and Bournier 1997, Dutton *et al*., 2002), psyllids (Hemiptera: Psyllidae), scale insects (Hemiptera: Coccoidea) Mansell (1998), mites (Acari), lepidopteran eggs and larvae (Mansell 1998, Michel and Bournier 1997, Dutton *et al*., 2002), whiteflies (Cauquil 1988, Michel and Bournier 1997) and mealybugs (Hemiptera: Aleyrodidae) Michel and Bournier (1997). All Chryso-perla spp. adults (Neuroptera: Chrysopidae) are pollen feeders Picker *et al*., (2003). Ladybirds prey on aphids (Cauquil 1988, Fürsch 1998, Picker *et al*.,2003, Michel and Bournier 1997), whiteflies Cauquil (1988), mealybugs (Hemiptera: Pseudococcidae) Fürsch (1998), scale insects (Fürsch 1998, Picker *et al*., 2003), psyllids and mites (Cauquil 1988, Fürsch 1998, Picker *et al*., 2003).

Lady bird beetle fauna of cotton fields is very diverse in different regions of the world (Ellis and Bradley 1992, Ellsworth *et al*., 1994). Predaceous coccinellids are linked to biological control more often than any other taxa of predatory organisms. The beneficial status of these organisms has a rich history that is recognized by the general public and biological control practitioners alike (Hussey and Scopes, 1985; Dixon, 2000). The lady bird beetles are important natural enemies of pest species, especially whiteflies, aphids, mealy bugs, scales and mites (Obrycki and Kring, 1998). The role of naturally occuring Coccinellidae in suppressing pest populations is significant but poorly doccumented in many pest management programs that purport to conserve natural enemies (Hodek and Honek, 1996).

There are several factors that influence the insect infestation, among them the temperature, relative humidity, wind speed and sun shine are great importance. The abundance of insect pests depends on season length, rainfall, temperature, surrounding vegetation, and agronomic practices (e.g., pest management) (Pimentel and Wheeler, 1973; Wilson, 1994).

The present study was formulated to study the entomofauna and changing insects scenario on cotton crop. The objective of the study was then to determine the species diversity and seasonal abundance of entomofauna in cotton agro ecosystem in and around Nanguneri, Tirunelveli District, Tamil Nadu during the study periods.

Objectives

The objectives of the present study is-

- To make a survey of the insect diversity of cotton in selected cotton agroecosystems in Nanguneri taluk of Tirunelveli District.
- To observe the insect diversity and its population month wise throughout the life cotton plant (from month 1 to 8).
- To identify the insects with standard key with the help of experts and categorize them taxonomically.
- To evaluate the population dynamics of insects belonging to various insect orders.
- To calculate the biodiversity indices to identify the abundance, richness and dominance throughout the life span of cotton plant.
- To identify the major pests of cotton and other beneficial insects and their abundance in relation to the age of cotton plant.

CHAPTER 2
REVIEW OF LITERATURE

The insects, class Insecta, are by far the largest group of organisms on earth, whether measured in terms of number of species or numbers of individuals. Insects live in every conceivable habitat on land and in fresh water, and a few have even invaded the sea. More than half of all the named animal species are insects, and the actual proportion is doubtless much higher because millions of additional forms await detection, classification, and naming. Approximately 90,000 described species occur in the United States and Canada, and the actual number of species in this area probably approaches 125,000. A hectare of lowland tropical forest is estimated to be inhabited by as many as 41,000 species of insects, and many suburban gardens may have 1500 or more species. Most insects are terrestrial (live on land), and are found in places such as trees, shrubs, flowers, rocks, logs, soil, buildings, and especially our gardens. Everyone is familiar with common terrestrial insects such as butterflies, moths, beetles, ants, bees, wasps, grasshoppers, crickets, cockroaches and flies.

Insects are important because of their diversity, ecological role and influence on agriculture, human health, and natural resources Berenbaum (1995); Adeduntan *et al* (2005); Premalatha *et al*., (2011). They have been used in landmark studies in biomechanics, climate change, developmental biology, ecology, evolution, genetics, paleolimnology, and physiology. They make up more than 58% of the known global biodiversity. They can be found in various types of habitat and contribute to the function and stability of ecosystems Godfray(2002). There is a tight association between insects and our lives. On the other hand, many insect species, including those who are still unkown, become continuously extinct or extirpated through-out the world

Miller *et al*., (2001). Insect species diversity is an important factor in the balance of environmental condition Yi Z *et al*., (2012).

Insect diversity and abundance play significant roles in the functioning of terrestrial and freshwater ecosystems. Insects affect the nutrient and energy flow of ecosystems in many ways; most essentially as decomposers. Burnie (2005) noted that insects are attractive animals, they outnumbered humans by over a billions times, and they make up over a half of all the animal species on the earth. Moreover, many insects are to be revealed, scientists believe; and have recognized more than one million species. Also, they categorized insects into groups known as orders. Within each order, they shared the same form and features. The major orders include Hymenoptera, Hemiptera, Diptera, Coleoptera, Lepidoptera, Odonata and Orthoptera. BarbosaI *et al.*, (2005) pointed out that the distribution of the insect orders in all habitations are extensive, globally. Besides, insects constitute the most varied group of organisms on the planet.

Insects are so many and so diverse that the study of this single group is a major field of biology called entomology. Insects consist of the most diverse and the attractive group of multicellular organisms on the earth, and they contribute significantly to most ecological functions such as pollination, nuisance control, decomposition, and maintenance of wildlife species (Losey and Vaughan, 2006). According to Weisser and Siemann (2004), within terrestrial ecosystems, insects functions as herbivores, pollinators, seed disperser, predators, parasites, detritivores or ecosystem engineers.

Insects are important natural capitals, particularly in the tropical rainforest ecosystems. They play an essential role, efficiently as pollinators and natural/biological pest control agents. Meanwhile, some insect species are significant pointers in ecosystem management (Rosina *et al.,* 2014). Agro-biodiversity, in addition, provides other essential ecosystem goods and services as well as maintaining habitats for pollinators as well as other useful insects. As soil engineers, insects reduce soil water overflow (Musgrave, 2013), and furthermore said, soil organic substances provides the necessary nutrients and can as well as raise biodiversity of soil microbes.

Samways (2005) pointed out that insects are the major modifiers and controllers of the physical state of abiotic and biotic materials. In this manner, they may be regarded as ecosystem engineers. According to Stewart *et al*., (2007), in addition to the provision of food to other organisms, insects are also food for humans. They furthermore noted that insect pollinators are necessary for more than 65% of the world's angiosperm species.

Insect are fundamental regulators of other organisms, principally other insects and plants as such; they can provide both direct benefits to human welfare during regulation of crops pests and victims through crop damage. Insect are major contributors to decomposition of vegetable and animal resources from the dung beetles that bury dung, carrion beetles and flies that feed on dead animals, termite and leafcutter. Several insects are detritus feeders that break down dead plant and animal tissue and return it to the surroundings as excretory products or as a food item for other aquatic animals. Very few are highly voracious and feed on fish, tadpoles also are other larger creatures (Willian, 2000).

Nichols *et al.,* (2008) noted that in terrestrial ecosystems, insects play important ecological roles in diverse ecological processes which include nutrient cycling, seed dispersal, bioturbation, and pollination. Furthermore, they pointed out that wherever insect is directly applicable to humans, this ecosystem frequently functions, which supply important as well as economically beneficial ecological unit services. Concluded, that they are as well major prey for a lot of vertebrates and of course for many invertebrates, including other insects. They provide a large food source. Even in fresh water, the function of insects is pivotal, with the fly-fishing industry to name one, being built on the useful role of insects as food.

Insects form a hyperdiverse taxonomic category contributing to more than half of terrestrial species diversity. As a rough estimate, some 30,000 insect species live in European forests. They respond to the structural complexity of forests at different temporal and spatial scales and are markedly influenced by natural and anthropogenic disturbances such as windthrow, logging and fragmentation. Due to their short turnover cycles, they are sensitive to and react rapidly to changes in their environment. With few exceptions, taxonomic or functional groups rather than single species have been used as indicators in forests. These include ants (Formicidae), butterflies and moths (Lepidoptera), hover flies (Syrphidae), parasitic wasps (Terebrantes), and most of all beetles, in particular ground beetles (Carabidae), longhorned beetles (Cerambycidae), saproxylic beetles in general, and dung beetles (part of Scarabaeidae). Among the numerous environmental factors known to affect species diversity, such as breeding substrate, food supply or canopy openness/insolation, the amount and quality of deadwood is the most important prerequisite for saproxylic insects and has therefore been the most investigated. There is hardly any quantitative information for other habitat requirements of forest insects.

The abundance of insects and distribution are regulated by numerous biotic and abiotic factors and interactions. Insect abundance is important because it regulated the ecosystem of insect communities. Insects are connected with numerous biotic and other peculiar adaptations, in addition, plastic responses (Savopoulous *et al*., 2012). The occurrence and abundance of insects may directly reflect environmental changes (Wahizatul, *et al.,* 2011). They furthermore noted that indicators species are those taxa species identified to be primarily sensitive to precise environmental factors. Therefore, their occurrences or abundance changes might directly reflect the environmental changes.

The distribution, abundance and richness of insect species can be influenced by the climate, vegetation and their interactions (Wolda 1978; Marinoni and Ganho 2003; Kittelson 2004; Torres and Madi-Ravazzi 2006). Food resources and climate conditions vary in space and time, directly affecting the diversity and distribution of insect populations (Morais *et al.* 1999; Kittelson 2004; Bispo *et al.* 2006; Bispo and Oliveira 2007; Goldsmith 2007). Climate is one of the determining factors in insect population fluctuations during the year (Wolda 1978; Torres and Madi-Ravazzi 2006).

Seasonal pattern can be defined as a phenomenon such as the abundance of active adults, appearance of reproductive activity or of dispersal may occur only at certain times of the year or it may occur year-round. In the latter case it is still considered seasonal if there are well-defined seasonal maxima (Wolda 1988). Variation in insect abundance in tropical regions is a well established fact (Wolda 1978; Wolda 1980; Wolda and Fisk 1981; Pinheiro *et al.* 2002), but little is known about the factors that determine this seasonality. In the tropics there is variation of climate conditions that can affect the seasonal patterns of insects (Wolda and Fisk 1981). One of the most important factors in many regions is the change from the dry to the rainy season (Wolda 1988).

Biological communities have a degree of organization that is represented by their specific abundance distribution or relative frequency of the species present in the environment. The biological diversity in one biological community has two components: species richness (existing species number) and homogeneity, which depends on the larger or smaller uniformity of the distribution frequency of existing species (Hurlbert, 1971). The importance of the use of diversity indexes is their application in monitoring studies of biological communities dynamics and structural change detection, when the community environment is modified and the species have to adapt to the modifications, so as to contribute with the conservation of biodiversity in agroecosystems (Southwood,1995).

Hammond (1990) found that 25% of this beetle fauna was associated with the soil/leaf litter for the major (feeding) part of their life cycle. Of the British insect fauna, arguably the best known in the world, probably 10% of the 22,000 species are closely associated with the soil and leaf litter, and possibly another 15% are loosely associated (e.g., many Lepidoptera pupate in the soil).

Diversity varies from local to global scales, and can be defined in many ways. Due to the difficulty of studying unseen organisms in the soil matrix, many measures of diversity aboveground, especially abundance, cannot be easily used belowground. While both species richness (the number of species) and diversity (the number and abundance of species) are easily measured aboveground, until very recently only species richness was estimable belowground for most organisms(De Deyn and Van der Putten, 2005). Except for a few recent studies Arun, (2003); Kunte, *et al.* (1999), information on seasonality of insects is grossly lacking from the Western Ghats region, one of the two internationally recognized biodiversity hotspots of the Indian region. However, accounts of the seasonal abundance of insects are available in many of the ecological studies, of India Vijayan (1975), Gaston (1978), Shukkur (1978), Vijayan (1984) Vijayan, (1991) and Sundaramoorthy (1991).

The temporal fluctuations in the abundance are an important manifestation of populations' response to the environmental conditions. Such seasonal fluctuations are especially prominent in the populations of lower organisms such as insects. Mackay and Kalf (1969), Danilevskii (1965), Ezhoe (1995), Frith and Frith (1985) and Kato *et al.,* (1995). Insects are generally more sensitive to environmental changes and the various distinct life-history stages of insects are adaptively timed according to the seasonal environmental conditions Parker and Courtney (1983).

Insects impress not only by their immense species richness but also by their variety of life forms: the four largest insect orders, Coleoptera, Diptera, Lepidoptera and Hymenoptera, represent major functional groups such as herbivores, pollinators, parasitoids and predators(Strong *et al*., 1984). The diversity of both species and life forms make insect communities an important part of terrestrial ecosystems. Plant–insect interactions become even more complexdue to parasitoids and predators which attack herbivores and pollinators. In addition, vertebrate top predators and megaherbivores may affect plant–invertebrate food webs (Tscharntke, 1997, Dicke and Vet, 1999).

The putative role of plant diversity in contributing to insect diversity has been discussed by a number of authors (Hutchinson, 1959, Southwood, 1966 and Hunter and Price, 1992). Primarily these authors focused on whether plant diversity influences the diversity insect herbivores (Strong *et al.,* 1984). For example, Southwood suggested that variation in habitats (plant communities) through time and space provides variation that supports multiple species (Southwood, 1977, 1988 and Southwood *et al*., 1979). More recent studies have demonstrated that changes in plant diversity alter not only herbivore diversity, but also insect predator and parasitoid diversity (Siemann, 1998 and Knops *et al*., 1999).

The richness of tropical insect fauna is beyond all earlier expectations (Stork 1988). Insects are the major components of animal diversity in terms of number of species in most of the habitats and ecosystems. With the growing awareness the world over for the need to understand and conserve biological diversity, there has been interest in evaluating the insect richness and diversity of the Indian fauna (Gadagkar *et al*. 1990, Muralirangan *et al*. 1993 and Sanjayan 1993). Acridids cause extensive damage to both agroecosystem (COPR 1982) and rangeland ecosystem (Hewitt and Onsanger 1983).

Biodiversity depends to a great extent on the conservation value of human-dominated and seminatural habitats, in a mixed agricultural landscape in southern Costa Rica, a total numbers 5976 arthropods representing 20 orders were recorded by Goehring *et al*., (2002). In the entomological collection of the Biological Sciences Faculty of Juárez University of Durango State, a total 570 specimens were collected, of which 192 seemed to be distinct species belonging to 57 families in 10 orders have been reported by Márquez-Hernández *et al*., (2014). Rosina Kyerematen *et al*. (2014) invented of species diversity of insects of the Muni-Pomadze Ramsar site, a total of 134 families from 19 insect orders from Kogyae Strict Nature Reserve and in Ghana a total of 8147 individuals representing 135 families from 21 orders.

In selected habitats of Wadakkanchery area a total of 58 species and 529 individual insects belonging to nine orders and 38 families were sighted by Usha and Vimala (2015). Ananthaselvi *et al*., (2009) reported the occurrence from the agricultural ecosystem in some southern districts of Tamil Nadu, a total thirty-one species of acridids were identified belonging to the families Acrididae and Pyrgomorphidae, the family Acrididae represented by 25 species (10 subfamilies and 22 genera) and the family Pyrgomorphidae comprised of six species (five genera). Orthoptera of Kanchipuram district along with their known distribution which includes 12 species/subspecies of belonging to 9 genera under 2 suborder, 3 superfamilies, 3 families and 7 subfamilies have been reported by Prabakar *et al*., (2015).

Anacardium occidentale in Benin,West Africa, a total 262 different insect species were recorded that belonged to the orders Hemiptera, Coleoptera, Hymenoptera, Diptera, Orthoptera, Lepidoptera, Isoptera, Neuroptera, Dermaptera, Odonata, and Thysanoptera have been recorded by Agboton *et al*., 2014. Kuukyi and Wiafe (2016) made survey and collection of insects in ten farms of Northern Ghana Region from December 2014 to April 2015, the insect density was found to be 6161/ha in farms closer to the forest, insects were represented 6 orders 20 families and 56 different species.

Thanasingh and Ambrose (2011) documented biodiversity and distribution of entomofaunal complex in 3 different ecosystem i.e in agroecosystem, a semi arid region and a scrub jungle in Thoothukudi district of Tamil Nadu, reported from the Sawyerpuram agro ecosystem with 244 species of insects from 106 families and 211 genera, the Vagaikulam semi arid region yielding 195 species from 165 genera and 96 families and the Vallanad Scrub jungle contributed 185 species from 91 families and 163 genera. Homoptera and Blattaria were found abundant in the semi arid zone, Orthoptera and Isoptera in the scrub jungle and Coleoptera, Heteroptera, Lepidoptera and Odonata were dominant in the agro-ecosystem.

Xavier Innocent and Merlin Dayana (2012) reported the occurrence from Sugarcane field at Allinagaram village, Periyakulam in Theni District, Tamil Nadu, India a total of 2660 insects belonging to 44 species and 10 orders. Diptera recorded a maximum density of 1650 insect with a population percentage of 62% followed by Lepidoptera with 12 species and a population percentage of 10.6%. Shah and Mitra (2014) also conducted a preliminary study of insect diversity of the proposed city forest area in Andaman and Nicobar Islands was carried out during September 2011, a total of 53 species of insects belonging 50 genera of 20 families under 6 orders have been recorded. Of them predominant order was Lepidoptera (45%, 24 species), followed by Odonata (23%, 12 species), Hymenoptera (13%, 7 species), Coeloptera and Diptera (each 8%, each 4 species) and Orthoptera (4%, 2 species).

Insect Diversity and Population in Agricultural Ecosystem Region Mountain, Kauditan District Area North Minahasa is a total of 39 individuals consisting of 6 orders and 6 families, with the amount of each individual as follows : Hemiptera 7, 12 Diptera, Hymenoptera 5, 4 Coleoptera, Lepidoptera 6, .and Orthoptera 5 The density populations the highest of the agricultural ecosystem that is on the order Diptera Family Lauxalidae have been recorded by Redsway Maramis *et al*., (2016).

Aland *et al*., (2012) made a study of diversity of beetles in and around Amba Reserve Forest of Kolhapur District Maharashtra. Incidentally, the study region is a part of Western Ghats which is included in hottest hotspots of the world. During the present surveys and collection a total of 152 species distributed over 101 genera belonging to 25 families of beetles were recorded. The same authors have reported of Hymenoptera was 82 species distributed over 47 genera and belonging to 17 families. The families Formicidae and Eumenidae were dominant with 39 and 11 species respectively.

Nikam and More (2016) made surveys and collection of insects in Jangamhatti area, Chandgad, Kolhapur district of Maharashtra in the years 2014 to 2015. During the study period, 44 species of insects belonging to 9 orders were reported. The order Lepidoptera was dominant with 18 species followed by Hemiptera, Coleoptera, Orthroptera, Hymenoptera, Odonata, Diptera, Mantodea and Blattodea with 9,6,4,2,2,1,1, and 1 species respectively.

Tahira ruby *et al*., (2010) reported Mixed-crop zone was highly diversified with respect to species and abundance of individuals per species. On the whole order Orthoptera was dominant followed by Araneae, Hemiptera, Coleoptera, Lepidoptera, Hymenoptera, Odonata, Diptera and Thysanoptera, Neuroptera, Prostigmata each represented by single species except Mantodea with two species. This data base will be helpful in future ecological pest management strategies. The mixed-crop zone was found better than cotton-wheat zone with respect to faunal diversity that may be functional in keeping the sustainability of agro-ecosystem.

The consecutive survey by Mohammad Kamil Usmani *et al.,*(2012) in two states of India i.e. Bihar and Jharkhand are based on paddy and pulses cultivars during 2009 and 2011. Bihar's economy is agrarian while in Jharkhand, agriculture is the mainstay of tribal population. During the survey it was observed that the paddy and pulses grown in the area were highly infested with grasshoppers. Samples collected were sorted out to yield 34 grasshopper species belonging to 25 genera, 2 families, 10 subfamilies and 19 tribes. Maximum number of grasshoppers collected belongs to subfamily Oedipodinae (9 species) followed by Oxyinae (4 species), Acridinae (4 species), Gomphocerinae (3 species), Catantopinae (3 species), Cyrtacanthacridinae (3 species), Pyrgomorphinae (3 species), Tropidopolinae (2 species), Hemiacridinae (2 species) with least number in case of Spathosterninae (1 species). Sixtus Iwan Umboh, 2016, this study aims to assess the diversity and insect populations in agricultural ecosystems. Sequens of this study consisted of determining the location of the sample, the sample unit, and agricultural ecosystems. This research was conducted using survey methods, identification and analysis data.The result study showed that abundance, insect populations and diversity obtained from agricultural ecosystem is a total of 39 individuals consisting of 6 orders and 6 families, with the amount of each individual as follows : Hemiptera 7, 12 Diptera, Hymenoptera 5, 4 Coleoptera, Lepidoptera 6, .and Orthoptera 5 The density populations the highest of the agricultural ecosystem that is on the order Diptera Family Lauxalidae.

A total of 30 Diptera of three families including, Asilidae (8 species), Syrphidae (6 species) and Tachinidae (16 species) had been reported by Hassan Ghahari *et al*., (2008). Of these, 8 tachinid species are new records for Iran.

A total of nine species of mantids belonging to the genera *Creobroter, Humbertiella, Eremoplana, Deiphobe, Hierodula* and *Schizocephala* have been reported feeding on moths, caterpillars, grasshoppers, jassids, scales, mealy bugs, white flies, aphids and termites on various economically important crop plants (Sathe and Patil Vaishali 2014).

A total of 33 species of Odonates were recorded from the study area from March to August, 2014. The family Libellulidae with 21 species was the most dominant among the Anisoptera (dragonflies) followed by Gomphidae (2 sp.) and Aeshnidae (1 sp.). Among the Zygoptera (damselflies), the 9 species recorded belong to the family Coenagrionidae. As the area houses 33 species of Odonates including 24 species of Anisoptera and 9 species of Zygoptera (Atanu Bora and Meitei 2014).

Dolly Kumar and Bhumika Naidu (2010) made a survey of the agricultural fields and urban ecosystems in 62 gardens and agricultural fields around Vadodara. The results show that this city sustains a good diversity of 58 species, 51 genera and 22 families of hemipterans. Agricultural fields and urban areas had higher abundance and diversity of the families viz, Pentatomidae, Coriedae, Reduviidae and Aphididae, whereas families Lophopidae, Cicadidae, Dinidoridae and Acanthosomatidae were less in number. Turnover diversity along habitats was found to be same.

Rituraj Saikia *et al*.,(2016) Visual counted and catch per unit effort was adopted to record the odonate diversity in the rice field. 68 individuals of odonate belonging to 14 species, equal number of species were recorded from each sub-order, Zygoptera and Anisoptera. The study revealed more number of damselfly population (40) than the dragonfly (28). Vegetative growth of rice crop support more number of Odonates (17 damselfly and 10 dragonfly) followed by reproductive (15 damselfly and 10 dragonfly) and ripening stage (8 damselfly and 8 dragonfly). The most dominant damselfly and dragonfly species were *Ceriagrion coromandelianum* and *Diplacodes trivialis* with 11 and 10 individuals respectively. Reported 6 orders 20 families and 56 different species in Cashew (*Anacardium occidentale* L.) Plants in the Flowering and Fruiting Periods in Northern Ghana by Kuukyi and Wiafe (2016).

Dadmal and Suvarna Khadakkar. (2014) invented 19 species of scarab beetles belonging to 10 genera were found. A total of 29,049 insects were collected during the study period i.e. 2011-12 (15350) and 2012-13 (13699), respectively. Among various insects collected in the trap, the major contributors were Coleopterans, Hemipterans, Lepidopterans, Orthopterans and Hymenopterans.

Twelve species of damselflies under 08 genera of 05 families were found, harboring in district Buner, including family Calopterygidae (represented by one species, *Neurobasis chinensis chinensis* Linnaeus); family Chlorocyphidae (having two genera represented by two species, *Libellago lineata lineata* Burmeister, *Rhinocypha quadrimaculata* Selys); family Coenagrionidae (including seven species *Ceriagrion coromandelianum* Fabricius, *Pseudagrion ceylanicum* Kirby, *P. rubriceps* Selys, *Ischnura aurora rubilio* Selys, *I. elegans* Vander Linden, *I. forcipata* Morton, *I. fountainei* Morton in three genera); family Protoneuridae (having a single species, *Elattoneura campioni* Fraser); and family Chlorolestidae (represented by a single species, *Megalestes major* Selys) (Naeem Zada *et al*., 2016).

Veeramuthu Anbalagan *et al*., (2015) The study revealed the presence of 100 species and 37 families of hymenoptera in the area of Tiruvallur District, Tamil Nadu. Totally 4994 individuals were sampled during the study period. Formicidae was the most dominant family in the study area. Braconidae, Encyrtidae, Eulophidae and Platygastridae were also found to be dominant in the vegetable fields.

Field survey were conducted by Ohnmar Khaing *et al*. (2002) at Suwan Farm, Northeastern Thailand during two growing periods of 2000 and 2001 to determine the species diversity and abundance of insect pests of cotton Although a total of 28 species invented on cotton, only 13-14 insect pests appeared in the cotton field.

Bal Harit and Dhawan, (2009) studies the arthropod fauna in the cotton agroecosystem during 2006 at two locations in the Entomological Research Farm, Punjab Agricultural University, Ludhiana and farmers field at Mansa district of Punjab. Arthropods were collected from aerial plant parts only by using various sampling methods such as standard sweep nets, aerial nets, beat buckets and whole plant inspections. 134 species of arthropods, including Hymenoptera (23.9%), Hemiptera (19.4%), Coleoptera (16.4%), Lepidoptera (14.2%), Orthoptera (8.2%), Diptera and spiders (4.5% each), Odonata (2.9%), Dictyoptera, Isoptera and mites (1.5% each) and Neuroptera and Thysanoptera (0.7% each) were found to be associated with cotton crop. Nangpal (1948) recorded nearly 109 species of insects and mites which infest cotton in India while, Sohi (1964) listed 137 insect and mite pests harbouring the cotton Crop in India.

Lady beetles (Coleoptera: Coccinellidae) are one of the powerful and dominant predators in cotton fields and also other agroecosystems (Hassan ghahari *et al*., 2009). The fauna of these beneficial insects was studied in cotton fields and surrounding grasslands of Iran through 2000-2006. Totally, 40 species from 17 genera (including *Adalia, Anisosticta, Brumus, Chilocorus, Clitostethus, Coccinella, Cryptolaemus, Delphastus, Exochomus, Hippodamia, Nephaspis, Nephus, Oenopia, Propylea, Rodolia, Scymnus* and *Stethorus*) were collected from different regions of Iran. In

Thailand, about 33 different species were recorded in cotton and only 13 species are known to damage cotton each year (Cantelo and Pholboon, 1965; Nachapong *et al*., 1989).

In order to understand the seasonal occurrence and activity of insect pest on cotton, studies were carried out at Cotton Research Institute, AARI, Faisalabad during 2009 By Shahid *et al., (*2012). On June 30, 2009, maximum thrips (31±1.15/leaf), mites population (35.33±2.72/leaf) was recorded and whitefly (21.33±2.85/leaf) was recorded during the whole month of August but abundant population of jassid (3.33±0.33/leaf) was during October. In general three months viz., May, June and July boosted Thrips and mites population beyond the economic threshold level (ETL). Jassid and whitefly population remained above ETL throughout observation period except during April when its activity was comparatively lower.

The cotton mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) has been reported occurring in several countries causing severe losses in economically important crops, including cotton (Carlos Alberto Domingues da Silva 2012). Based on information reported by farmers in the regions of the Southwest and Middle São Francisco, Bahia and also in the regions of the Agreste and Semi-arid of the Paraiba State, high infestations of cotton mealybugs have occurred in these regions during the cotton season of 2007 and 2008. The cotton mealybug was identified as *P. solenopsis* and this represents the first record of this insect attacking cotton in Brazil.

Soil arthropod community was investigated by using pitfall and compared the abundance and diversity of arthropods in Bt-cotton and non Bt-cotton fields of Warangal, Andhra Pradesh, India from June 2011 to March 2012 have been reported by Chintha Sammaiah *et al*.,(2014). A total of 46 specimens in non Bt cotton and 40 in Bt-cotton (Collembola, Ants, Beetles, Crickets, Spiders and Mites) were captured and identified. The largest number of individuals was collected in both crops. In Thailand, about 33 different species were recorded in cotton and only 13 species are known to damage cotton each year (Cantelo and Pholboon, 1965; Nachapong *et al*., 1989). The abundance of insect pests depends on season length, rainfall, temperature, surrounding vegetation, and agronomic practices (e.g., pest management) (Pimentel and Wheeler, 1973; Wilson, 1994).

Cotton crop is inhabited by numerous insect species and is generally recognized that various insect predator species play an important role in regulating pest populations. Cotton ecosystem provides home to about 1326 species of insects from sowing to maturity in different cotton growing areas of the world (Hargreaves, 1948 and Atwal, 2002). Out of which Nangpal (1948) recorded nearly 109 species of insects and mites, Sohi (1964) listed 137 insect and mite pests, 166 species were recorded in India by Khan and Rao,(1960), while in sub-continent it is infested by 162 species of insect and mite pests (Manjunath, 2004), 134 species of arthropods were recorded in India by Bal Harit and Dhawan, (2009) and about 200 in India have been recorded as pests of cotton (Balakrishnan *et al*., 2010).

CHAPTER 3
MATERIALS AND METHODS

3.1 Location of the Study Area

The Entomofauna studies of cotton field were carried out at Koonthankulam, Moolaikaraipatti and Chinthamani of Nanguneri Taluk, Tirunelveli District, Tamil Nadu. The details of the materials used and methodology followed during the course of investigations are described in this chapter. The study area was located in Nanguneri Taluk in the District of Tirunelveli situated at a distance of 18 miles (29 km) from the headquarters of the District. Nanguneri is located at a latitude of 8°29'45.98"N and a longitude of 77°38'47.23"E (Fig.1). To achieve holistic profile of the insect fauna three representative sites were selected for surveys and collection of insects. They were Kunthankulam, Moolaikaraipatti and Chinthamani where cotton was grow periodically (Plate 1). This has helped to depict the data and analyze techniques in a lucid manner. These three sites represented various physical conditions such as soil texture and water quality.

3.2 Season and sowing time

As an irrigated crop, cotton was cultivated in summer seasons in Nanguneri. Cotton was sown in February and Harvested in June to August. It is a major fibre crop of global importance and has high commercial value. Cotton is grown commercially in the temperature and tropical region. Genus *Gossypium* (family Malvaceae), namely *Gossypium hirsutum* L. (Plate 2).

3.3 Soil

The soil is loamy soils spread over the Nanguneri. Cotton can be grown in mixed soils. Loam is soil composed mostly of sand, silt, and clay. Loam soils generally contain more nutrients, moisture, and humus than sandy soils, have better drainage and infiltration of water and air than silt and clay-rich soils, and are easier to till than clay soils. Loam soil is suitable for growing cotton plant.

3.4 Meteorological data

The meteorological data such as maximum and minimum temperatures, relative humidity and total rainfall for the study period were obtained from Agro Climate Research Center, Tamil Nadu Agricultural University, Coimbatore. The monthly average of meteorological data of the study area for the entire study period is given in the Table 1.

Maximum and Minimum temperature

The highest maximum temperature (37.9 °C) was recorded during April 2016 and the lowest (23.3°C) during February2015.

Relative humidity(RH)

The range of relative humidity was between 46.1% and 77.8% during 2015 and 2016 respectively.

Rainfall

Rain fall was experienced continually almost every month during the study period. Maximum rainfall (126 mm) was recorded during April 2015 and minimum (3 mm) during April and June 2016.

Table 1. Meteorological parameters during the study period

Month	Temperature(°C)		Relative Humidity (%)	Rainfall (mm)
	Max.	Min.		
February 2015	32.8	23.3	69.7	0
March 2015	34.6	24.9	71.7	77.5
April 2015	34.7	25.3	77.8	126
May 2015	35.6	26.1	73.2	37.2
June 2015	36.5	26.7	61.2	72
July 2015	37.2	27.5	50	3.1
August 2015	37.1	27.1	51.7	29
September 2015	35.6	26.4	63.7	72
February 2016	33.2	24.4	70.2	0
March 2016	36.1	25.8	68.8	0
April 2016	37.9	26.8	67.9	3
May 2016	36.9	26.9	64.6	0
June 2016	35.5	27.1	55.2	3
July 2016	36.3	27.7	51	12.4
August 2016	37	28.2	46.1	0
September 2016	37.2	28	44.7	0

3.5 Field Surveys

The field surveys were truly aimed at listing the insect fauna at selected sampling stations within three sites of study region; with a view to study their ecological as well as biological characters especially their species richness of the orders. The initial field visits were undertaken to understand the physical environment of study area and to identify sites and locations within them. Later on series of field visits to each of the location were organized for a period of a month so as to enable proper sighting and collection of insects.

3.6 Study Period

The investigation was carried out for period from February 2015 to September 2015 and February 2016 to September 2016. The surveillance of cotton crop was initiated at the seedling emergence of the crop and continued until the life span.

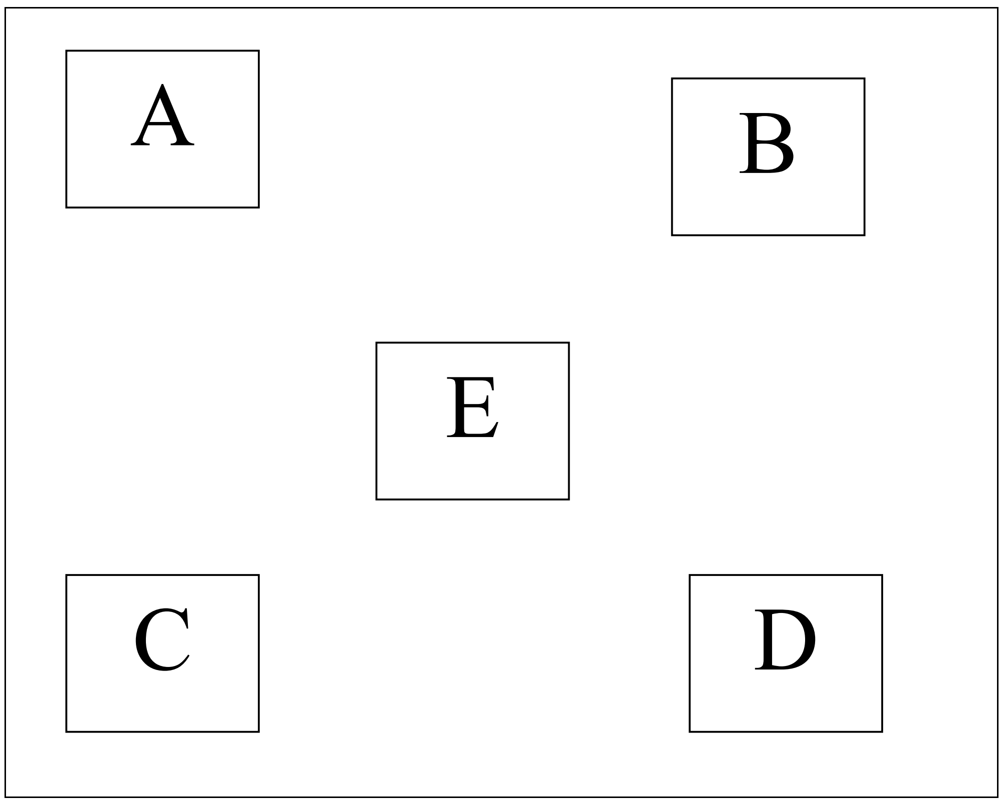
3.7 Sampling and collection strategies

Sampling was conducted twice in every month at the selected cotton (entire life span) field. The five collection points randomly in the plot were in the center and one at each cardinal point. Adult insects were collected by using the following sampling methods: Quadrate Method, Hand picking, entomological net, light trap, pitfall trap and direct sampling. Collected insects were placed into containers of 70% ethanol. The insects were recorded and photographed.

3.7.1Quadrate Method (Figure 2)

The sampling was done in the morning (06.00AM -12.30 PM) and evening (03.00pm-06.30pm) with quadrate method. The method of Southwood (1978) and Magurran (1988) were also taken into account to collect and analyze insect fauna. For productive insect sampling, quadrates of size 10mx10m were selected which were constant at all cotton fields and they were selected randomly.

Figure 2. Quadrate Method



Cotton field

3.7.2 Hand picking

Insects were collected by hand with the help of a fine forceps. The forceps was used carefully to avoid damage to the insect. The collected insects were preserved for identification.

3.7.3 Light Trap

Light trap (Plate 3-A) was used to collect insects normally attracted towards light. The trap consisted of a plastic funnel of one metre diameter with a light source of 200 W mercury vapour lamp. At the bottom of the funnel, the killing jar, saturated with the killing agent ethanol was placed. The light trap was set at the ground in the middle of cotton agroecosystern. It was run fortnight between 18.00 and 06.00 hrs (Edwin 1997). The light attracted insects were collected in the killing jar.

3.7.4 Pitfall trap

Pitfall trap (Plate 3-B) is a simple but very effective and useful type of interception trap. Ground moving (walking and crawling) insects were collected by pitfall trap method. The traps were set up early morning and kept overnight, after 24 hours the traps were retrieved. These traps were used throughout the study period. Pitfall trap consisted of a single plastic jar (top diameter = 15 cm, height = 20cm) buried in the ground surface. The killing agent ethanol was placed in the receptacle.

3.8 Identification of Insects

Based on the inherent complexity of the taxonomy, morphological characteristics were used to identify the specimens to species per family of each order. The collected specimens were identified using the taxonomic keys of Kirby (1914), Borror and White (1970), Bland and Jaques (1978), Slater and Baranwski (1978), Arnett *et al*. (1980), Leahy and White (1987), Milne and Milne (1992), Domínguez (1998 a,b,c), Triplehorn and Johnson (2005), Subramanian (2005), Eaton and Kaufman (2007), Evans (2008), Kiran and David (2013) and also specimens were identified with help of Entomologyst from Project Coordinator (Cotton Improvement) and Head, Central Institute for Cotton Research, Regional Station, Maruthamalai Road, Coimbatore; Professor, Head, Dept. of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore and Professor and Head, Dept. of Agricultural Entomology, Agricultural College; Research Institute, Killikulam,Vallanadu, Thoothukudi District, Tamil Nadu, India.

3.9 Grading System

Assessment of Mealy bugs and aphids population abundance in cotton field. Since the present investigation had recorded a high percentage of order Hemiptera during the survey the season for the same was deduced. It was observed the aphids and mealy bugs were responsible for such abundance. Hence assessment of aphids and mealy bugs population were carried out through grading system.

3.10 Statistical analysis

Species diversity is defined as the number of species present in an area. The values can be used to assess the health of the environments. The species diversity is calculated by Shannon diversity index the method by using *Biodiversity pro software*.

3.10.1 Shannon diversity index (Shannon, 1948)

$$H' = - \sum_{i} p_i \ln (p_i)$$

Where Pi = proportion of the number of individuals of species to the total number of individuals ($P_i = n_i / N$)

n = total number of species.

N = total number of individuals

n1and n2 are the respective number of individuals of each species

The lower the index, lower the diversity, whereas higher the index, higher the

diversity, species richness and evenness. The high species diversity indicates healthy environment.

3.10.2 Species richness (S)

Species richness means number of species present in an ecosystem. Species richness S is the simplest measure of biodiversity and is simply a count of the number of different species in a given area. This measure is strongly dependent on sampling size and effort. Two species richness indices try to account for this problem.

3.10.3 Evenness (J)

Evenness J = Hmax’ /Log^2 S

Where, Hmax’ = is the Shannon maximum diversity index

S = the total number of species in the sample.

It’s a measure of how similar is the abundance of different species/categories in a community.

Evenness is ranged from zero to one when evenness is close to zero; it

indicates that most of the individuals belong to one or a few species/categories. When the evenness is close to one, it indicates that each species/categories consists of the same number of individuals.

3.10.4 Hill Numbers (Hill, 1973)

It show the relation between the species richness indices and the evenness indices

Ho = S (species richness)

H1 = exp H' exponential of Shannon diversity Indices

3.10.5 Berger-Parker Dominance index

$d = N_{max} / N$

N_{max} = the number of individuals in the most abundant species

N = the total number of individuals in the sample

It is simple measure of the numerical importance of the most abundant species. The reciprocal of the index, 1/d, is often used, so that an increase in the value of the index accompanies an increase in diversity and a reduction in dominance.

3.11 Cluster analysis

Cluster analysis was performed using Bray-Curtis similarity (Single link). Insects order contributing individuals of the total abundance at each sampling site were included in the analysis.

CHAPTER 4
RESULTS

Cotton is a crop which has a life span of seven to eight months approximately usually grown in dry seasons. In Nanguneri taluk cotton plantation is cultivated by the end of January and harvested by the month of June to August. Growth period of cotton and insect population studies from the first month of plantation has been surveyed. Month wise growth of cotton plant is given in Plate 4.

4.1.1 Insect population dynamics and diversity of Kunthankulam cotton agrosystem

Field survey of Kunthankulam from February 2015 to September 2015 and February 2016 to September 2016 revealed a total insect population of 11805 and 6886 respectively representing 10 insect orders (Table 2 and Table 3). The insect orders observed were Blattodea, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Mantodea, Neuroptera, Odonata and Orthoptera. Throughout the entire study period insects belonging to order Hemiptera was prevalent (8823 and 4756) followed by Hymenoptera (1784 and 1108) and Coleoptera (459 and 374). The next dominant group of insects came under the orders Diptera, Orthoptera and Odonata, Lepidoptera which was followed by Mantodea and Neuroptera. Order Blattodea represented the least population which ranged from 1 to 2 or 4 individuals.

An observation of table 2 and 3 revealed that the population dynamics of Hemiptera reached the peak during July 2015 with a maximum of 2454 individuals. It was the same during July 2016 also with a population dynamics of 1370 individuals. Across all stages of growth of the cotton plant, a steady increase in insect population was observed irrespective of the orders. However the insect population was high as the plant reached maturity and the cotton bolls were becoming ripe and declined towards post harvest period.

Among the total population of insects in Kunthankulam cotton fields highest percentage was represented by order Hemiptera (71% to 75%) followed by Hymenoptera (15% to 17%) and Coleoptera (4% to 6%) (Figure 3). Other insect orders represented a meagre percentage (Diptera 2%, Orthoptera 2%, Lepidoptera 1%, and Odonata 1%).

Table 2. Population dynamics of various insect orders in the cotton field at Kunthankulam during February 2015 to September 2015

Insect Orders	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Blattodea	0	0	0	2	3	2	2	4	13
Coleoptera	16	32	64	92	69	82	63	41	459
Diptera	3	14	28	33	19	24	46	61	228
Hemiptera	110	208	620	783	1687	2454	1846	1115	8823
Hymenoptera	89	153	179	128	260	372	306	297	1784
Lepidoptera	2	8	19	24	29	18	16	14	130
Mantodea	0	2	5	12	6	8	3	2	38
Neuroptera	0	0	3	7	8	6	9	4	37
Odonata	0	9	16	20	34	27	13	15	134
Orthoptera	3	6	19	28	37	21	25	20	159
Total	223	432	962	1131	2152	3014	2332	1573	11805

Table 3. Population dynamics of various insect orders in the cotton field at Kunthankulam during February 2016 to September 2016

Insect Orders	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Blattodea	0	0	0	1	1	2	0	2	6
Coleoptera	21	35	49	52	73	57	58	29	374
Diptera	0	2	4	7	10	26	37	44	130
Hemiptera	65	237	360	488	622	1370	1017	597	4756
Hymenoptera	27	113	159	176	121	219	175	118	1108
Lepidoptera	0	0	4	16	19	11	6	12	68
Mantodea	0	1	5	8	6	4	7	3	34
Neuroptera	0	0	0	4	2	1	6	2	15
Odonata	1	4	5	9	16	20	14	9	78
Orthoptera	2	3	12	18	26	31	17	13	122
Total	101	300	473	718	974	2017	1446	865	6886

4.1.2 Species Composition in Kunthankulam cotton field

A total of 116 species of insects from 97 genera and 60 families (Table 4) were collected from Kunthankulam cotton agroecosystem. Order Blattodea was represented by only one species belonging to family Blattellidae,

Order Coleoptera recorded nineteen species from sixteen genera and nine families, Coccinellidae was the predominant family with seven species followed by family Scarabaeidae with four species, Families Curculionidae, Chrysomelidae, Meloidae, Cetonidae, Carabidae, Tenebrionidae, and Dermestidae were least represented with one species each. In Order Diptera eleven species from nine genera and nine families were recorded, Family Tabanidae and Muscidae (two species each), Families Calliphoridae, Asilidae, Stratiomyidae, Chironomidae, Dolichopodidae, Tachinidae and Syrphidae were least represented by single species only.

A total number of nineteen species belonging to fifteen genera and nine families were collected in the sub-order Heteroptera (order Hemiptera). Among Hemiptera, family Pyrrhocoridae, Coreidae and Geocoridae each with three species followed by Alydidae, Pentatomidae, Reduviidae and Scutelleridae each with two species, Lygaeidae and Miridae one species. Seven species of sub-order Homoptera(order Hemiptera) belonging to seven genera and five families were collected in this ecosystem. Except family Aleyrodidae and Membracidae with two species all the other four families were represented by one species each.

Twenty five species of Hymenoptera belonging to sixteen genera and eleven families were collected. Formicidae was the predominant family with nine species followed by families Vespidae, Sphecidae and Apidae (three species each), Aphelinidae, Xylocopidae, Scoliidae, Chalcididae, Braconidae, Figitidae, Halictidae and Ichneumonidae families were the least represented families with one species each.

Order Lepidoptera was represented by ten species from ten genera and six families. Nymphalidae family three species were recorded followed by the families Noctuidae and Pieridae(two species each), Gelechiidae, Crambidae and Papilionidae were least represented with one species each. Three species of Mantodea were collected from two genera and two families. The families Mantidae with two species and family Hymenopodidae were represented with one species.

In Order Neuroptera only one species was recorded belonging to family Chrysopidae. Seven species of Odonata belonged to seven genera and three families were collected. Family Libellulidae was represented by four species followed by Coenagrionidae with two species and Coenagriidae with one species. Thirteen species of Orthoptera from twelve genera and four families were collected from the cotton field. Acrididae was the most highly distributed family with eight species followed by Pyrgomorphidae (three species), Gryllidae and Tetrigidae with one species each.

Table 4. List of different species of insects observed in the cotton fields at Kunthankulam

S. No.	Scientific name	Family
	Order : Blattaria	
1.	*Blattella* sp.	Blattellidae
	Order: Coleoptera	
2.	*Brumoides suturalis* (Fabricius)	Coccinellidae
3.	*Rodolia cardinalis* (Mulsant)	Coccinellidae
4.	*Rodolia fumida (*Fabricius)	Coccinellidae
5.	*Cheilomenes sexmaculatus (*Fabricius)	Coccinellidae
6.	*Cheilomenes propinqua* (Mulsant)	Coccinellidae
7.	*Micraspis discolor* (Fabricius)	Coccinellidae
8.	*Coccinella transversalis* (Fabricius)	Coccinellidae
9.	*Coccinella* sp.	Coccinellidae
10.	*Chiloloba acuta* (Widemann)	Scarabaeidae
11.	*Diplotaxis* sp.	Scarabaeidae
12.	*Onthophagus* sp.	Scarabaeidae
13.	*Rhinyptia nigrifrons* (Kraatz)	Scarabaeidae
14.	*Mylabris indica* (Thunberg)	Meloidae
15.	*Myllocerus discolor* (Boheman)	Curculionidae
16.	*Raphidopalpa Foveicollis* (Lucas)	Chrysomelidae
17.	*Oxycetonia versicolor* (Fabricius)	Cetonidae
18.	*Ophionea indica* (Thunberg)	Carabidae
19.	*Gonocephalum* sp.	Tenebrionidae
20.	*Anthrenus* sp.	Dermestidae
	Order: Diptera	
21.	*Tabanus* sp.	Tabanidae
22.	*Tabanus striatus* (Fabricius)	Tabanidae
23.	*Musca* sp.	Muscidae
24.	*Musca domestica* (Linnaeus)	Muscidae
25.	*Philodicus* sp.	Asilidae
26.	*Calliphora* sp.	Calliphoridae
27.	*Hedriodiscus* sp.	Stratiomyidae

28.	*Chironomus* sp.	Chironomidae
29.	*Condylostylus* sp.	Dolichopodidae
30.	*Tachinid* sp.	Tachinidae
31.	*Eristalinus aequalis* (Adams)	syrphidae
	Order: Hemiptera (Suborder: Homoptera)	
32.	*Bemisia tabaci* (Gennadius)	Aleyrodidae
33.	*Aleurodicus dispersus* (Russell)	Aleyrodidae
34.	*Leptocentrus* sp.	Membracidae
35.	*Oxyrachis tarandus* (Fabricius)	Membracidae
36.	*Amrasca biguttula biguttula* (Ishida)	Cicadellidae
37.	*Aphis gossypii* (Glover)	Aphididae
38.	*Phenacoccus solenopsis* (Tinsley)	Pseudococcidae
	Order: Hemiptera (Suborder: Heteroptera)	
39.	*Cletus* sp.	Coreidae
40.	*Oxycarenus hyalinipennis* (Costa)	Coreidae
41.	*Leptocorisa acuta* (Thunberg)	Coreidae
42.	*Dysdercus cingulatus* (Fabricius)	Pyrrhocoridae
43.	*Dysdercus koenigii* (Fabricius)	Pyrrhocoridae
44.	*Antilochus coquebertii*(Fabricius)	Pyrrhocoridae
45.	*Geocoris erythrocephalus* (Lepeletier & Serville)	Geocoridae
46.	*Geocoris punctipes* (Say)	Geocoridae
47.	*Geocoris* sp.	Geocoridae
48.	*Nezara viridula* (Linnaeus)	Pentatomidae
49.	*Dolicoris* sp.	Pentatomidae
50.	*Rhaphidosoma* sp.	Reduviidae
51.	*Rhynocoris fuscipes* (Fabricius).	Reduviidae
52.	*Riptortus* sp.	Alydidae
53.	*Riptortus pedestris* (Fabricius)	Alydidae
54.	*Calidea* sp.	Scutelleridae
55.	*Chrysocoris stollii* (Wolff)	Scutelleridae
56.	*Graptostethus servus* (Fabricius)	Lygaeidae
57.	*Creontiades biseratense* (Distant)	Miridae

	Order: Hymenoptera	
58.	*Polyrhachis simplex* (Mayr)	Formicidae
59.	*Camponotus compressus* (Fabricius)	Formicidae
60.	*Camponotus sericeus* (Fabricius)	Formicidae
61.	*Camponotus rufoglaucus* (Jerdon)	Formicidae
62.	*Camponotus irritans* (Smith, F.)	Formicidae
63.	*Camponotus* sp.	Formicidae
64.	*Monomorium* sp.	Formicidae
65.	*Monomorium indicum* (Forel)	Formicidae
66.	*Monomorium minimum* (Buckley)	Formicidae
67.	*Chalybion bengalense* (Dahlbom)	Sphecidae
68.	*Liris* sp.	Sphecidae
69.	*Sceliphron* sp**.**	Sphecidae
70.	*Ropalidia* sp.	Vespidae
71.	*Ropalidia marginata* (Lepeletier)	Vespidae
72.	*Vespa affinis* (Linnaeus)	Vespidae
73.	*Apis indica* (Fabricius)	Apidae
74.	*Apis florea* (Fabricius)	Apidae
75.	*Apis mellifera* (Linnaeus)	Apidae
76.	*Encarsia formosa* (Gahan)	Aphelinidae
77.	*Xylocopa* sp.	Xylocopidae
78.	*Brachymeria* sp.	Chalcididae
79.	*Stenobracon nicevillei* (Bingham)	Braconidae
80.	*Callaspidia notata* (Fonscolombe)	Figitidae
81.	*Halictus* sp.	Halictidae
82.	*Campoletis* sp.	Ichneumonidae
	Order: Lepidoptera	
83.	*Danaus* sp.	Nymphalidae
84.	*Junonia almana* (Linnaeus)	Nymphalidae
85.	*Hypolimnas misippus* (Linnaeus)	Nymphalidae
86.	*Earias vittella* (Fabricius)	Noctuidae
87.	*Helicoverpa armigera* (Hubner)	Noctuidae
88.	*Eurema hecabe* (Linnaeus)	Pieridae
89.	*Catopsilia pyranthe* (Linnaeus)	Pieridae

90.	*Pectinophora gossypiella* (Saunders)	Gelechiidae
91.	*Scirpophaga incertulas* (Walker)	Crambidae
92.	*Papilio demoleus* (Linnaeus)	Papilionidae
	Order: Mantodea	
93.	*Mantis religiosa* (Linnaeus)	Mantidae
94.	*Hierodula patellifera* (Serville)	Mantidae
95.	*Odontomantis planiceps* (Giglio-Tos)	Hymenopodidae
	Order: Neuroptera	
96.	*Chrysoperla carnea* (Stephens)	Chrysopidae
	Order: Odonata	
97.	*Pantala flavescens* (Fabricius)	Libellulidae
98.	*Diplacodes trivialis* (Rambur)	Libellulidae
99.	*Orthetrum sabina* (Drury)	Libellulidae
100.	*Crocothemis servilia* (Drury)	Libellulidae
101.	*Pseudagrion rubriceps* (Selys)	Coenagrionidae
102.	*Ischnura aurora* (Brauer)	Coenagrionidae
103.	*Coenagrion puella* (Linnaeus)	Coenagriidae
	Order: Orthoptera	
104.	*Anacridium* sp. (Fabricius)	Acrididae
105.	*Trilophidia annulata* (Thunberg)	Acrididae
106.	*Aiolopus* sp.	Acrididae
107.	*Diabolocatantops pinguis* (Stål)	Acrididae
108.	*Chrotogonus* sp.	Acrididae
109.	*Chrotogonus oxypterus* (Blanchard)	Acrididae
110.	*Oxya hyla hyla* (Serville)	Acrididae
111.	*Cyrtacanthacris tatarica* (Linnaeus)	Acrididae
112.	*Atractomorpha crenulata* (Fabricius)	Pyrgomorphidae
113.	*Atractomorpha* sp.	Pyrgomorphidae
114.	*Neorthacris simulans* (Bolívar)	Pyrgomorphidae
115.	*Gryllus* sp.	Gryllidae
116.	*Tetrix* sp.	Tetrigidae

4.1.3 Indices of distribution and diversity in insects occupying Kunthankulam cotton field

Shannon diversity (H') in Kunthankulam cotton field during the study period February 2015- September 2015 and February 2016- September 2016 varied between 1.013 - 1.781 and 0.971-1.746 respectively (Table 5 and 6). It was higher in month of July (H'= 1.781 and 1.746), followed by in month of June (H'= 1.648 and 1.736), month of May and month of August (H'= 1.553 and 1.628), month of August and month of May (H'= 1.518 and 1.554). H' was Less in month of February (H'= 1.013 and 0.971).

The Shannon J'(evenness J') of insect had a range between 0.566 to 0.773. This was high in month of July (J = 0.773 and 0.758), less in month of February (J = 0.566) and month of March (J=0.603). Hill's Number H0 (Species richness) was in the range of 18-97, highest in month of July and least in month of February. The Hill's Number H1 (abundance %) of insect ranged between 5.853% – 18.83%. Similarly Berger-Parker Dominance (d%) varied between 49.327% and 81.42%, which was high in month of July (81.42%) and less in month of February (49.327%).

Table 5. Indices of distribution and diversity in insects occupying in Kunthankulam cotton field during February 2015 to September 2015

Indices	Pre mature plants			Mature plants			Old plants	
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Shannon Diversity H'	1.013	1.306	1.452	1.553	1.648	1.781	1.518	1.468
Shannon J' (Evenness J')	0.566	0.628	0.661	0.674	0.716	0.773	0.659	0.638
Berger-Parker Dominance (d%)	49.327	48.148	65.058	69.353	78.392	81.42	79.261	70.884
Hill's Number H0(Species Richness)	18	39	46	75	89	97	92	76
Hill's Number H1(Abundance %)	6.225	9.498	11.722	13.55	15.552	18.83	12.889	11.994

Table 6. Indices of distribution and diversity in insects occupying in Kunthankulam cotton field during February 2016 to September 2016

Indices	Pre mature plants			Mature plants			Old plants	
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Shannon Diversity H'	0.971	1.075	1.285	1.554	1.736	1.746	1.628	1.472
Shannon J' (Evenness J')	0.603	0.552	0.618	0.675	0.754	0.758	0.741	0.639
Berger-Parker Dominance (d%)	56.034	60	60.201	62.644	69.42	78.69	76.066	72.014
Hill's Number H0(Species Richness)	15	36	45	70	78	91	87	73
Hill's Number H1(Abundance %)	5.853	6.799	9.214	13.571	17.646	17.908	15.099	12.056

4.2.1 Insect population dynamics and diversity of Moolaikaraipatti cotton agroecosystem

Month-wise surveys in the second site of our investigation i.e., Moolaikaraipatti from February 2015 to September 2015 and in the succeeding year February 2016 to September 2016 also showed a similar trend in the diversity of insects (Table 7 and Table 8). It also recorded the same insect order except for the population dynamics.

A total insect population of 8916 and 5109 representing 10 insect orders was recorded during the two years of survey. Hemiptera possessed the highest population dynamics (6698 and 3478) followed by Hymenoptera (1189 and 975) and Coleopteran (379 and 290). The next dominant group of insects came under the orders Diptera, Orthoptera, Odonata and Lepidoptera which was followed by Mantodea and Neuroptera. Order Blattodea represented the least population dynamics which ranged from 1 to 2 or 3 individuals.

Analysis of table 7 and 8 revealed that the population dynamics of Hemiptera reached the peak during July 2015 with a maximum of 1977 individuals. It was the same during July 2016 also with a population dynamics of 1276 individuals. Throughout the period of growth right from the first month onwards the cotton plants envisaged a gradual increase in the insect population in all insect Orders. However compared to the previous ecosystems the population dynamics in less. During both years of survey orders coleopteran, Hemiptera and Hymenoptera dominated the insect population.

Figure 4 gives the percentage composition of insect orders in Moolaikaraipatti cotton agrosystems during the period of study. Here, also order Hemiptera was high with a percentage ranging from 68% to 75%. Order Hymenoptera ranged from 13% to 19%. Coleoptera represented 4% to 6% of the total insect population whereas other insect order were represented by meagre percentage.

Table 7. Population dynamics of various insect orders in the cotton field at Moolaikaraipatti during February 2015 to September 2015

Insect Orders	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Blattodea	0	0	1	1	2	1	2	3	10
Coleoptera	22	46	53	86	43	75	34	20	379
Diptera	0	13	19	14	13	47	42	38	186
Hemiptera	82	166	448	604	1015	1977	1543	863	6698
Hymenoptera	42	111	164	131	194	166	217	164	1189
Lepidoptera	0	2	14	22	25	21	14	12	110
Mantodea	0	0	4	8	11	9	7	4	43
Neuroptera	0	0	2	6	13	5	3	2	31
Odonata	3	6	10	14	27	21	15	26	122
Orthoptera	6	10	23	26	30	24	17	12	148
Total	155	354	738	912	1375	2346	1894	1144	8916

Table 8. Population dynamics of various insect orders in the cotton field at Moolaikaraipatti during February 2016 to September 2016

Insect Orders	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Blattodea	0	0	1	0	1	3	2	1	8
Coleoptera	15	19	37	41	45	70	47	16	290
Diptera	2	0	3	5	8	20	32	29	99
Hemiptera	34	66	111	154	462	1276	996	379	3478
Hymenoptera	32	68	71	118	194	142	216	134	975
Lepidoptera	2	4	3	13	18	15	12	9	76
Mantodea	0	2	6	3	0	4	0	1	16
Neuroptera	0	0	2	1	3	0	2	3	11
Odonata	0	2	3	5	8	14	16	5	53
Orthoptera	0	4	14	16	13	28	17	11	103
Total	85	165	251	356	752	1572	1340	588	5109

4.2.2 Species Composition in Moolaikaraipatti cotton field

A total of 106 species of insects from 92 genera and 59 families (Table 9) were collected from Moolaikaraipatti cotton agroecosystem. Order Blattodea was represented by only one species belonging to family Blattellidae,

Order Coleoptera recorded twenty species from eighteen genera and twelve families, Coccinellidae, Curculionidae and Chrysomelidae with three species each, followed by Scarabaeidae and Meloidae (two species each), Families Cetonidae, Carabidae, Tenebrionidae, Cassidinae and Dermestidae were represented with one species each. In Order Diptera twelve species from nine genera and six families were recorded, Family Calliphoridae (four species), Muscidae with three species, Tabanidae(two species) and Family Sarcophagidae, Tachinidae and Syrphidae with a single species each.

A total number of nineteen species belonging to sixteen genera and nine families were collected in the sub-order Heteroptera (order Hemiptera). Among Heteroptera, families Pyrrhocoridae, Coreidae, Lygaeidae and Geocoridae each with three species followed by families Scutelleridae and Miridae with two species each, families Alydidae, Pentatomidae and Reduviidae one species each. Seven species of sub order Homoptera(order Hemiptera) belonging to seven genera and five families were collected in this ecosystem. Except family Membracidae and Aleyrodidae with two species all the other four families were represented by one species each.

Eighteen species of Hymenoptera belonging to fourteen genera and ten families were collected. Family Formicidae represented four species, followed by families Apidae and Vespidae with three species, family Sphecidae (two species), Scoliidae, Braconidae, Figitidae, Bethelidae, Halictidae and Ichneumonidae families were the least represented families with one species each.

Order Lepidoptera was represented by six species from six genera and five families. Family Pieridae two species were recorded followed by the families Noctuidae, Nymphalidae, Gelechiidae and Crambidae were least represented with one species each. Three species of Mantodea were collected from three genera and two families. The families Mantidae consisted of two species and Liturgusidae was represented with one species.

In Order Neuroptera only one species was recorded belonging to family Chrysopidae. Seven species of Odonata belonging to seven genera and three families were collected. Family Libellulidae consisted of five species followed by families Coenagrionidae and Coenagriidae with one species each. Twelve species of Orthoptera from ten genera and four families were collected from the cotton field. Acrididae was the most highly distributed family with seven species followed by Pyrgomorphidae (three species), Gryllidae and Tetrigidae (one species each).

Table 9. List of different species of insects observed in Moolaikaraipatti cotton fields

S. No.	Scientific name	Family
	Order : Blattaria	
1.	*Blattella* sp.	Blattellidae
	Order: Coleoptera	
2.	*Rodolia fumida* (Mulsant)	Coccinellidae
3.	*Cheilomenes sexmaculatus* (Fabricius)	Coccinellidae
4.	*Micraspis discolor* (Fabricius)	Coccinellidae
5.	*Myllocerus discolor* (Boheman)	Curculionidae
6.	*Myllocerus undecimpustulatus* (Marshall)	Curculionidae
7.	*Rhynchophorus palmarum* (Linnaeus)	Curculionidae
8.	*Raphidopalpa Foveicollis* (Lucas)	Chrysomelidae
9.	*Cryptocephalus* sp.	Chrysomelidae
10.	*Acanthoscelides* sp.	Chrysomelidae
11.	*Mylabris indica* (Thunberg)	Meloidae
12.	*Mylabris pustulata* (Thunberg)	Meloidae
13.	*Diplotaxis* sp.	Scarabaeidae
14.	*Onthophagus* sp.	Scarabaeidae
15.	*Oxycetonia versicolor* (Fabricius)	Cetonidae
16.	*Paederus fuscipes* (Curtis)	Staphilinidae
17.	*Ophionea indica* (Thunberg)	Carabidae
18.	*Gonocephalum* sp.	Tenebrionidae
19.	*Aspidomorpha* sp.	Cassidinae
20.	*Agriotes* sp.	Elateridae
21.	*Anthrenus* sp.	Dermestidae
	Order: Diptera	
22.	*Chrysomya megacephala* (Fabricius).	Calliphoridae
23.	*Chrysomya* sp.	Calliphoridae
24.	*Calliphora* sp.	Calliphoridae
25.	*Lucilia* sp.	Calliphoridae

26.	*Musca domestica* (Linnaeus)	Muscidae
27.	*Musca* sp.	Muscidae
28.	*Limnophora* sp.	Muscidae
29.	*Tabanus* sp.	Tabanidae
30.	*Tabanus striatus* (Fabricius)	Tabanidae
31.	*Sarcophaga* sp.	Sarcophagidae
32.	*Tachinid* sp.	Tachinidae
33.	*Eristalinus aequalis* (Adams)	Syrphidae
	Order: Hemiptera (Suborder: Homoptera)	
34.	*Bemisia tabaci* (Gennadius)	Aleyrodidae
35.	*Aleurodicus dispersus* (Russell)	Aleyrodidae
36.	*Leptocentrus* sp.	Membracidae
37.	*Oxyrachis tarandus* (Fabricius)	Membracidae
38.	*Amrasca biguttula biguttula* (Ishida)	Cicadellidae
39.	*Aphis gossypii* (Glover)	Aphididae
40.	*Phenacoccus solenopsis* (Tinsley)	Pseudococcidae
	Order: Hemiptera(Suborder: Heteroptera)	
41.	*Dysdercus cingulatus* (Fabricius)	Pyrrhocoridae
42.	*Dysdercus koenigii* (Fabricius)	Pyrrhocoridae
43.	*Antilochus coquebertii* (Fabricius)	Pyrrhocoridae
44.	*Cletus* sp.	Coreidae
45.	*Oxycarenus hyalinipennis* (Costa)	Coreidae
46.	*Leptocorisa acuta* (Thunberg)	Coreidae
47.	*Graptostethus servus* (Fabricius)	Lygaeidae
48.	*Dieuches* sp.	Lygaeidae
49.	*Lygaeus* sp.	Lygaeidae
50.	*Geocoris erythrocephalus* (Lepeletier and Serville)	Geocoridae
51.	*Geocoris punctipes* (Say)	Geocoridae
52.	*Geocoris* sp.	Geocoridae
53.	*Calidea* sp.	Scutelleridae
54.	*Chrysocoris stollii* (Wolff)	Scutelleridae

55.	*Malacocoris* sp.	Miridae
56.	*Pseudatomoscelis seriatus* (Reuter)	Miridae
57.	*Riptortus* sp.	Alydidae
58.	*Nezara viridula* (Linnaeus)	Pentatomidae
59.	*Rhynocoris fuscipes* (Fabricius).	Reduviidae
	Order: Hymenoptera	
60.	*Solenopsis* sp.	Formicidae
61.	*Polyrhachis simplex* (Mayr)	Formicidae
62.	*Camponotus compressus* (Fabricius)	Formicidae
63.	*Camponotus irritans* (Smith, F.)	Formicidae
64.	*Ropalidia* sp.	Vespidae
65.	*Ropalidia marginata* (Lepeletier)	Vespidae
66.	*Delta* sp.	Vespidae
67.	*Apis indica* (Fabricius)	Apidae
68.	*Apis florea* (Fabricius)	Apidae
69.	*Apis mellifera* (Linnaeus)	Apidae
70.	*Chalybion bengalense* (Dahlbom)	Sphecidae
71.	*Liris* sp.	Sphecidae
72.	*Scolia* sp.	Scoliidae
73.	*Stenobracon nicevillei* (Forel)	Braconidae
74.	*Callaspidia notata* (Fonscolombe)	Figitidae
75.	*Halictus* sp.	Halictidae
76.	*Bethylus* sp.	Bethylidae
77.	*Campoletis* sp.	Ichneumonidae
	Order: Lepidoptera	
78.	*Eurema hecabe* (Linnaeus)	Pieridae
79.	*Catopsilia pyranthe* (Linnaeus)	Pieridae
80.	*Helicoverpa armigera* (Hubner)	Noctuidae
81.	*Pectinophora gossypiella* (Saunders)	Gelechiidae
82.	*Junonia almana* (Linnaeus)	Nymphalidae
83.	*Scirpophaga incertulas* (Walker)	Crambidae

	Order: Mantodea	
84.	*Mantis religiosa* (Linnaeus)	Mantidae
85.	*Hierodula patellifera* (Serville)	Mantidae
86.	*Humbertiella* sp.	Liturgusidae
	Order: Neuroptera	
87.	*Chrysoperla carnea* (Stephens)	Chrysopidae
	Order: Odonata	
88.	*Pantala flavescens* (Fabricius)	Libellulidae
89.	*Orthetrum sabina* (Drury)	Libellulidae
90.	*Trithemis pallidinervis* (Kirby)	Libellulidae
91.	*Urothemis signata* (Rambur)	Libellulidae
92.	*Crocothemis servilia* (Drury)	Libellulidae
93.	*Pseudagrion rubriceps* (Selys)	Coenagrionidae
94.	*Coenagrion puella* (Linnaeus)	Coenagriidae
	Order: Orthoptera	
95.	*Trilophidia annulata* (Thunberg)	Acrididae
96.	*Spathosternum prasiniferum* (Walker)	Acrididae
97.	*Aiolopus* sp.	Acrididae
98.	*Chrotogonus* sp.	Acrididae
99.	*Acrida exaltata* (Walker)	Acrididae
100.	*Acrida* sp.	Acrididae
101.	*Oxya hyla hyla* (Serville)	Acrididae
102.	*Atractomorpha crenulata* (Fabricius)	Pyrgomorphidae
103.	*Atractomorpha* sp.	Pyrgomorphidae
104.	*Neorthacris simulans* (Bolívar)	Pyrgomorphidae
105.	*Gryllus* sp.	Gryllidae
106.	*Tetrix* sp.	Tetrigidae

4.2.3 Indices of distribution and diversity in insects occupying Moolaikaraipatti cotton field

Shannon diversity (H’) in Moolaikaraipatti cotton field during the study period February 2015 to September 2015 and February 2016 to September 2016 varied between 1.084 - 1.765 and 0.975-1.623 respectively (Table 10 and 11). It was higher in month of July (H’= 1.765 and 1.623), followed by in month of June (H’= 1.732 and 1.509), month of May (H’= 1.705 and 1.493), month of April and month of August (H’= 1.591 and 1.491). H’ was Less in month of February (H’= 1.084 and 0.975).

The Shannon J’(evenness J’) of insect had a range between 0.606 to 0.767. This was high in month of July (J = 0.767 and 0.739), less in month of February (J = 0.673 and 0.606). Hill’s Number H0 (Species richness) was in the range of 10-90, highest in month of July and least in month of February. The Hill’s Number H1 (abundance %) of insect ranged between 6.532% – 18.408%. Similarly Berger-Parker Dominance(d%) varied between 40% and 84.271%, which was high in month of July (84.271% and 81.17%) and less in month of March and February (46.893% and 40%).

Table 10. Indices of distribution and diversity in insects occupying in Moolaikaraipatti cotton field during February 2015 to September 2015

Indices	Pre mature plants			Mature plants			Old plants	
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Shannon Diversity H'	1.084	1.36	1.591	1.705	1.732	1.765	1.547	1.477
Shannon J' (Evenness J')	0.673	0.699	0.691	0.741	0.752	0.767	0.672	0.642
Berger-Parker Dominance (d%)	52.903	46.893	60.705	66.228	73.926	84.271	81.468	75.437
Hill's Number H0(Species Richness)	14	36	42	75	84	90	82	68
Hill's Number H1(Abundance %)	6.888	10.266	14.314	16.895	17.565	18.408	13.436	12.156

Table 11. Indices of distribution and diversity in insects occupying in Moolaikaraipatti cotton field during February 2016 to September 2016

Indices	Pre mature plants			Mature plants			Old plants	
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Shannon Diversity H'	0.975	1.243	1.28	1.493	1.509	1.623	1.491	1.094
Shannon J' (Evenness J')	0.606	0.639	0.556	0.68	0.687	0.739	0.679	0.475
Berger-Parker Dominance (d%)	40	41.212	44.223	43.258	61.436	81.17	74.328	64.456
Hill's Number H0(Species Richness)	10	32	39	64	80	88	76	67
Hill's Number H1 (Abundance %)	6.532	8.675	8.929	9.846	10.732	16.252	16.594	5.704

4.3.1 Insect population dynamics and diversity of Chinthamani cotton agroecosystem

Field observations in the cotton fields of Chinthamani village during the study period also showed a similar trend as that of the other two sites of investigation regarding the insect population and diversity (Table 12 and Table 13). Unlike the other ecosystems Chinthamani cotton agroecosystem recorded nine insect orders.

The insect orders observed were Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Mantodea, Neuroptera, Odonata and Orthoptera. Order Blattodea could not be observed in this site. Here also Order Hemiptera was abundant than other insect Orders. During February 2015 to September 2015 there was the highest incidence of Hemiptera (5205 individuals) compared to February 2016 to September 2016 (3502 individuals). Order hymenoptera recorded the next highest population of 1564 and 1224 during 2015 and 2016 respectively. The population of all insect orders except order Diptera and order Odonata declined after the month of July 2015. However in the second year of survey all insect orders declined except order Diptera fluctuation especially in the months of April, May and June 2016.

Graphical representation of the percentage of various insect orders in Chinthamani cotton agro-system during the period of survey is given in Figure 5. An in the other study areas here also order Hemiptera was the highest in population ranging from 65% to 68%. Order Hymenoptera represented 20% to 23% in the total insect population. Order Coleoptera with 5%, Orthoptera and Diptera with 2% and order Odonata and Lepidoptera with 1% represented the total insect population.

Table 12. Population dynamics of various insect orders in the cotton field at Chinthamani during February 2015 to September 2015.

Insect Orders	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Coleoptera	14	29	55	73	97	61	47	38	414
Diptera	4	10	25	15	10	19	36	44	163
Hemiptera	73	138	267	452	706	1518	1488	563	5205
Hymenoptera	114	137	152	177	254	329	284	117	1564
Lepidoptera	0	4	19	12	18	15	11	8	87
Mantodea	0	1	2	10	8	4	3	5	33
Neuroptera	0	0	0	3	6	3	0	6	18
Odonata	1	3	14	13	22	25	11	19	108
Orthoptera	0	4	16	33	24	19	16	14	126
Total	206	326	554	789	1141	1993	1899	816	7723

Table 13. Population dynamics of various insect orders in the cotton field at Chinthamani during February 2016 to September 2016.

Insect Orders	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Coleoptera	7	13	20	34	57	64	40	21	256
Diptera	0	4	7	14	11	19	38	24	117
Hemiptera	56	99	188	257	414	1330	752	406	3502
Hymenoptera	84	77	138	163	201	270	167	124	1224
Lepidoptera	0	2	3	7	13	17	11	8	61
Mantodea	0	0	2	5	3	6	2	3	21
Neuroptera	0	0	0	4	0	5	3	2	14
Odonata	2	5	6	8	12	24	15	7	79
Orthoptera	2	5	8	13	25	19	11	16	99
Total	151	205	372	505	736	1754	1039	611	5373

4.3.2 Species Composition in Chinthamani cotton field

Table 14 illustrates the entomofauna of the cotton agroecosystem in Chinthamani site A total of 83 species of insects were recorded which were categorized into 72 genera and 47 families.

Order Coleoptera consisted of sixteen species from fifteen genera and ten families, Coccinellidae family with four species followed by families Curculionidae, Chrysomelidae and Scarabaeidae with two species each, Families Meloidae, Staphilinidae, Carabidae, Tenebrionidae, Elateridae and Dermestidae were least represented with one species each. In Order Diptera eight species from seven genera and five families were recorded, Family Muscidae (three species), Calliphoridae family with two species and Families Tabanidae, Sarcophagidae and Syrphidae were least represented by single species only.

A total number of thirteen species belonging to Eleven genera and seven families were collected in the order Hemiptera(sub-order Heteroptera). Among

Heteroptera, family Pyrrhocoridae with three species followed by Pentatomidae, Coreidae, Lygaeidae and Geocoridae each families with two species and families Alydidae and Miridae with one species each. five species of sub-order Homoptera (order Hemiptera) belonging to five genera and four families were collected in this ecosystem. Except family Membracidae with two species all the other four families were represented by one species each.

Fourteen species of Hymenoptera coming under nine genera and six families were collected. Formicidae was the predominant family with six species followed by Apidae family with three species, Vespidae(two species) and Halictidae, Bethylidae and Ichneumonidae were the least represented families with one species each.

Categorization of Order Lepidoptera included six species from six genera and five families. Family Pieridae was represented by two species and Nymphalidae, Noctuidae, Gelechiidae and Hesperiidae families were least represented with one species each. Three species of Mantodea were collected from three genera and two families. The families Mantidae(two species) and Liturgusidae was represented with one species.

Order Neuroptera only one species was recorded belonging to family Chrysopidae. Six species of Odonata belonging to six genera and three families were collected. Under family Libellulidae three species were observed followed by Coenagrionidae family with two species and family Coenagriidae was one species. Eleven species of Orthoptera from nine genera and four families were collected from the cotton field. Acrididae was the most highly distributed family with five species followed by Pyrgomorphidae (four species), Gryllidae and Tetrigidae families with one species each.

Table 14. List of different species of insects observed in the cotton fields at Chinthamani

S. No.	Scientific name	Family
	Order: Coleoptera	
1.	*Rodolia fumida* (Fabricius)	Coccinellidae
2.	*Cheilomenes sexmaculatus* (Fab.)	Coccinellidae
3.	*Cheilomenes propinqua* (Mulsant)	Coccinellidae
4.	*Micraspis discolor* (Fabricius)	Coccinellidae
5.	*Myllocerus discolor* (Boheman)	Curculionidae
6.	*Rhynchophorus palmarum* (Linnaeus)	Curculionidae
7.	*Cryptocephalus* sp.	Chrysomelidae
8.	*Acanthoscelides* sp.	Chrysomelidae
9.	*Diplotaxis* sp.	Scarabaeidae
10.	*Rhinyptia nigrifrons* (Kraatz)	Scarabaeidae
11.	*Paederus fuscipes* (Curtis)	Staphilinidae
12.	*Ophionea indica* (Thunberg)	Carabidae
13.	*Gonocephalum* sp.	Tenebrionidae
14.	*Mylabris indica* (Thunberg)	Meloidae
15.	*Agriotes* sp.	Elateridae
16.	*Anthrenus* sp.	Dermestidae
	Order: Diptera	
17.	*Musca domestica* (Linnaeus)	Muscidae
18.	*Musca* sp.	Muscidae
19.	*Limnophora* sp.	Muscidae
20.	*Chrysomya* sp.	Calliphoridae
21.	*Calliphora* sp.	Calliphoridae
22.	*Tabanus striatus* (Fabricius)	Tabanidae
23.	*Sarcophaga* sp.	Sarcophagidae
24.	*Eristalinus aequalis* (Adams)	Syrphidae
	Order: Hemiptera (Suborder: Homoptera)	
25.	*Leptocentrus* sp.	Membracidae
26.	*Oxyrachis tarandus* (Fabricius)	Membracidae

27.	*Amrasca biguttula biguttula* (Ishida)	Cicadellidae
28.	*Aphis gossypii* (Glover)	Aphididae
29.	*Phenacoccus solenopsis* (Tinsley)	Pseudococcidae
	Order: Hemiptera (Suborder: Heteroptera)	
30.	*Dysdercus cingulatus* (Fabricius)	Pyrrhocoridae
31.	*Dysdercus koenigii* (Fabricius)	Pyrrhocoridae
32.	*Antilochus coquebertii*(Fabricius)	Pyrrhocoridae
33.	*Cletus* sp.	Coreidae
34.	*Oxycarenus hyalinipennis* (Costa)	Coreidae
35.	*Nezara viridula* (Linnaeus)	Pentatomidae
36.	*Dolicoris* sp.	Pentatomidae
37.	*Graptostethus servus* (Fabricius)	Lygaeidae
38.	*Dieuches* sp.	Lygaeidae
39.	*Geocoris erythrocephalus* (Lepeletier and Serville)	Geocoridae
40.	*Geocoris* sp.	Geocoridae
41.	*Creontiades biseratense* (Distant)	Miridae
42.	*Riptortus* sp.	Alydidae
	Order: Hymenoptera	
43.	*Solenopsis invicta* (Buren)	Formicidae
44.	*Solenopsis* sp.	Formicidae
45.	*Polyrhachis simplex* (Mayr)	Formicidae
46.	*Camponotus compressus* (Fabricius)	Formicidae
47.	*Tetraponera rufonigra* (Jerdon)	Formicidae
48.	*Tetraponera allaborans* (Walker)	Formicidae
49.	*Apis indica* (Fabricius)	Apidae
50.	*Apis florea* (Fabricius)	Apidae
51.	*Apis mellifera* (Linnaeus)	Apidae
52.	*Ropalidia* sp.	Vespidae
53.	*Ropalidia marginata* (Lepeletier)	Vespidae
54.	*Halictus* sp.	Halictidae
55.	*Bethylus* sp.	Bethylidae
56.	*Campoletis* sp.	Ichneumonidae

	Order: Lepidoptera	
57.	*Eurema hecabe* (Linnaeus)	Pieridae
58.	*Catopsilia pyranthe* (Linnaeus)	Pieridae
59.	*Helicoverpa armigera* (Hubner)	Noctuidae
60.	*Pectinophora gossypiella* (Saunders)	Gelechiidae
61.	*Junonia almana* (Linnaeus)	Nymphalidae
62.	*Pelopidas mathias* (Fabricius)	Hesperiidae
	Order: Mantodea	
63.	*Mantis religiosa* (Linnaeus)	Mantidae
64.	*Hierodula patellifera* (Serville)	Mantidae
65.	*Humbertiella* sp.	Liturgusidae
	Order: Neuroptera	
66.	*Chrysoperla carnea* (Stephens)	Chrysopidae
	Order: Odonata	
67.	*Pantala flavescens* (Fabricius)	Libellulidae
68.	*Orthetrum sabina* (Drury)	Libellulidae
69.	*Trithemis pallidinervis* (Kirby)	Libellulidae
70.	*Pseudagrion rubriceps* (Selys)	Coenagrionidae
71.	*Ischnura aurora* (Brauer)	Coenagrionidae
72.	*Coenagrion puella* (Linnaeus)	Coenagriidae
	Order: Orthoptera	
73.	*Trilophidia annulata* (Thunberg)	Acrididae
74.	*Aiolopus* sp.	Acrididae
75.	*Chrotogonus* sp.	Acrididae
76.	*Acrida exaltata* (Walker)	Acrididae
77.	*Acrida* sp.	Acrididae
78.	*Poecilocerus pictus* (Fabricius)	Pyrgomorphidae
79.	*Atractomorpha crenulata* (Fabricius)	Pyrgomorphidae
80.	*Atractomorpha* sp.	Pyrgomorphidae
81.	*Neorthacris simulans* (Bolívar)	Pyrgomorphidae
82.	*Gryllus* sp.	Gryllidae
83.	*Tetrix* sp.	Tetrigidae

4.3.3 Indices of distribution and diversity in insects occupying Chinthamani cotton field

Shannon diversity (H’) in Chinthamani cotton field during the study period February 2015 to September 2015 and February 2016 to September 2016 varied between 0.824 - 1.746 and 0.749-1.571 respectively (Table 15 and 16). It was higher in month of June and August (H’= 1.746 and 1.571), followed by in month of July and September (H’= 1.655 and 1.523), month of May and July (H’= 1.642 and 1.498), month of April and May (H’= 1.614 and 1.466). H’ was Less in month of February (H’= 0.824 and 0.749).

The Shannon J’(evenness J’) of insect had a range between 0.465 to 0.794. This was high in month of June and August (J = 0.794 and 0.715), less in month of February (J = 0.512 and 0.465). Hill’s Number H0 (Species richness) was in the range of 8-76, highest in month of August and least in month of February. The Hill’s Number H1 (abundance %) of insect ranged between 4.249% – 17.899%. Similarly Berger-Parker Dominance(d%) varied between 42.331% and 78.481%, which was high in month of August and July (78.481% and 75.827%) and less in month of March (42.331% and 48.293%).

Table 15. Indices of distribution and diversity in insects occupying in Chinthamani cotton field during February 2015 to September 2015

Indices	Pre mature plants			Mature plants			Old plants	
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Shannon Diversity H'	0.824	1.18	1.614	1.642	1.746	1.655	1.516	1.42
Shannon J' (Evenness J')	0.512	0.568	0.776	0.747	0.794	0.753	0.729	0.646
Berger-Parker Dominance (d%)	55.34	42.331	48.545	57.36	61.659	76.167	78.481	69.165
Hill's Number H0(Species Richness)	11	27	34	55	66	73	76	61
Hill's Number H1(Abundance%)	4.737	7.762	12.436	15.414	17.899	15.706	12.845	5.361

Table 16. Indices of distribution and diversity in insects occupying in Chinthamani cotton field during February 2016 to September 2016

Indices	Pre mature plants			Mature plants			Old plants	
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Shannon Diversity H'	0.749	1.249	1.215	1.466	1.459	1.498	1.571	1.523
Shannon J'(Evenness J')	0.465	0.642	0.584	0.667	0.701	0.682	0.715	0.693
Berger-Parker Dominance (d%)	55.629	48.293	50.538	50.891	56.25	75.827	72.377	66.448
Hill's Number H0(Species Richness)	8	23	30	49	57	66	62	58
Hill's Number H1(Abundance %)	4.249	8.741	8.323	11.954	11.834	12.521	13.914	12.975

4.4. Assessment of Mealy bugs and aphids population

Since the present investigation had recorded a high percentage of order Hemiptera during the survey the season for the same was deduced. It was observed the aphids and mealy bugs were responsible for such abundance. Hence assessment of aphids and mealy bugs population were carried out through grading system.

Plate 5 illustrates the population of mealy bugs during April to September 2015 and April to September 2016 grading of mealy bugs infestation as Grade 1, 2, 3 and 4. Grade 0 showed healthy plant and Grade 1 recorded 1-10 mealy bugs scattered over a branch of plant. In Grade 2 more than two branches of plant showed mealy bug population. In Grade 3 more branches infested. In grade 4 complete become infested with mealy bugs.

Grading of Aphid population was given in plate 6. Cotton leaves with aphids are categorised from grade 0-4 based on the abundance of aphids.

4.5.1 Overall insect population dynamics and diversity of Nanguneri Cotton Agro-system

Totally 28439 and 17368 insects were recorded in the cotton agro-systems of Nanguneri taluk of Tirunelveli District in the year 2015 and 2016 respectively. All the insect population observed were grouped under ten orders (Table 17 and 18). Order Hemiptera recorded the highest population of 20726 and 11931 during the survey. Order Hymenoptera was the second with a population of 4537 and 3307. Order Coleoptera ranged from 920 to 1252. Order Diptera recorded 577 and 346 insects and order Lepidoptera recorded 327 and 205 insects. Order Odonata with 364 and 210, order Orthoptera with 433 and 324 also constituted to the insect population. Order

Mantodea, Neuroptera and Blattodea, represented minimum numbers in the populations.

Summarizing the data obtained in the three different location of Nanguneri taluk of Tirunelveli district revealed 10 insect orders with 148 species and 123 genera coming under 68 families (Table 19). An observation of figure 16 showed that the order Hemiptera recorded highest percentage (71%) followed by order Hymenoptera (17 %) and order Coleoptera (5%). order Diptera with 2%, order Orthoptera with 2 % , order Odonata with 1 %, order Lepidoptera with 1 % represented the total insect population. Very less percentage of and order Mantodea with 1% Order Neuroptera and order Blattodea also constituted to the total insect population.

Table 17. Insect population dynamics in Nanguneri cotton field during 2015

Insect Orders	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Blattodea	0	0	1	3	5	3	4	7	23
Coleoptera	52	107	172	251	209	218	144	99	1252
Diptera	7	37	72	62	42	90	124	143	577
Hemiptera	265	512	1335	1839	3408	5949	4877	2541	20726
Hymenoptera	245	401	495	436	708	867	807	578	4537
Lepidoptera	2	14	52	58	72	54	41	34	327
Mantodea	0	3	11	30	25	21	13	11	114
Neuroptera	0	0	5	16	27	14	12	12	86
Odonata	4	18	40	47	83	73	39	60	364
Orthoptera	9	20	58	87	91	64	58	46	433
Total	584	1112	2241	2829	4670	7353	6119	3531	28439

Table 18. Insect population dynamics in Nanguneri cotton field during 2016

Insect Orders	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Blattodea	0	0	1	1	2	5	2	3	14
Coleoptera	43	67	106	127	175	191	145	66	920
Diptera	2	6	14	26	29	65	107	97	346
Hemiptera	140	307	534	838	1571	4249	2874	1418	11931
Hymenoptera	143	258	368	457	516	631	558	376	3307
Lepidoptera	2	6	10	36	50	43	29	29	205
Mantodea	0	3	13	16	9	14	9	7	71
Neuroptera	0	0	2	9	5	6	11	7	40
Odonata	3	11	14	22	36	58	45	21	210
Orthoptera	4	12	34	47	64	78	45	40	324
Total	337	670	1096	1579	2457	5340	3825	2064	17368

Table 19. Entomofauna of cotton Agroecosystem in Nanguneri

S. No.	Scientific name	Family
	Order : Blattodea	
1.	*Blattella* sp.	Blattellidae
	Order: Coleoptera	
2.	*Brumoides suturalis* (Fabricius, 1789)	Coccinellidae
3.	*Rodolia cardinalis* (Mulsant,1850)	Coccinellidae
4.	*Rodolia fumida* (Mulsant,1850)	Coccinellidae
5.	*Cheilomenes sexmaculatus* (Fabricius, 1781)	Coccinellidae
6.	*Cheilomenes propinqua* (Mulsant, 1850)	Coccinellidae
7.	*Micraspis discolor* (Fabricius, 1798)	Coccinellidae
8.	*Coccinella transversalis* (Fabricius,1789)	Coccinellidae
9.	*Coccinella* sp.	Coccinellidae
10.	*Chiloloba acuta* (Widemann, 1823)	Scarabaeidae
11.	*Diplotaxis* sp.	Scarabaeidae
12.	*Onthophagus* sp.	Scarabaeidae
13.	*Rhinyptia nigrifrons* (Kraatz,1895)	Scarabaeidae
14.	*Myllocerus discolor* (Boheman,1834)	Curculionidae
15.	*Myllocerus undecimpustulatus* (Faust, 1891)	Curculionidae

16.	*Rhynchophorus palmarum* (Linnaeus, 1758)	Curculionidae
17.	*Raphidopalpa Foveicollis* (Lucas, 1849)	Chrysomelidae
18.	*Cryptocephalus* sp.	Chrysomelidae
19.	*Acanthoscelides* sp.	Chrysomelidae
20.	*Mylabris indica* (Thunberg, 1784)	Meloidae
21.	*Mylabris pustulata* (Thunberg, 1821)	Meloidae
22.	*Oxycetonia versicolor* (Fabricius, 1775)	Cetonidae
23.	*Paederus fuscipes* (Curtis, 1826)	Staphylinidae
24.	*Ophionea indica* (Thunberg,1784)	Carabidae
25.	*Gonocephalum* sp.	Tenebrionidae
26.	*Aspidomorpha* sp.	Cassidinae
27.	*Agriotes* sp.	Elateridae
28.	*Anthrenus* sp.	Dermestidae
	Order: Diptera	
29.	*Chrysomya megacephala* (Fabricius, 1794).	Calliphoridae
30.	*Chrysomya* sp.	Calliphoridae
31.	*Calliphora* sp.	Calliphoridae
32.	*Lucilia* sp.	Calliphoridae
33.	*Musca domestica* (Linnaeus, 1758)	Muscidae
34.	*Musca* sp.	Muscidae
35.	*Limnophora* sp.	Muscidae
36.	*Tabanus* sp.	Tabanidae
37.	*Tabanus striatus* (Fabricius, 1787)	Tabanidae
38.	*Philodicus* sp.	Asilidae
39.	*Hedriodiscus* sp.	Stratiomyidae
40.	*Sarcophaga* sp.	Sarcophagidae
41.	*Chironomus* sp.	Chironomidae
42.	*Condylostylus* sp.	Dolichopodidae
43.	*Tachinid* sp.	Tachinidae
44.	*Eristalinus aequalis* (Adams, 1905)	Syrphidae
	Order: Hemiptera(Suborder: Homoptera)	
45.	*Bemisia tabaci* (Gennadius, 1889)	Aleyrodidae
46.	*Aleurodicus dispersus* (Russell 1965)	Aleyrodidae
47.	*Leptocentrus* sp.	Membracidae

48.	*Oxyrachis tarandus* (Fabricius)	Membracidae
49.	*Amrasca biguttula biguttula* (Ishida, 1913)	Cicadellidae
50.	*Aphis gossypii* (Glover,1877)	Aphididae
51.	*Phenacoccus solenopsis* (Tinsley,1898)	Pseudococcidae
	Order: Hemiptera (Sub-order: Heteroptera)	
52.	*Dysdercus cingulatus* (Fabricius,1775)	Pyrrhocoridae
53.	*Dysdercus koenigii* (Fabricius, 1775)	Pyrrhocoridae
54.	*Antilochus coquebertii*(Fabricius,1803)	Pyrrhocoridae
55.	*Cletus* sp.	Coreidae
56.	*Oxycarenus hyalinipennis* (Costa,1843)	Coreidae
57.	*Leptocorisa acuta* (Thunberg,1783)	Coreidae
58.	*Graptostethus servus* (Fabricius,1787)	Lygaeidae
59.	*Dieuches* sp.	Lygaeidae
60.	*Lygaeus* sp.	Lygaeidae
61.	*Malacocoris* sp.	Miridae
62.	*Creontiades biseratense (*Distant 1903*)*	Miridae
63.	*Pseudatomoscelis seriatus* (Reuter,1876)	Miridae
64.	*Geocoris erythrocephalus* (Lepeletier & Serville,1825)	Geocoridae
65.	*Geocoris punctipes* (Say,1832)	Geocoridae
66.	*Geocoris* sp.	Geocoridae
67.	*Riptortus* sp.	Alydidae
68.	*Riptortus pedestris* (Fabricius,1775)	Alydidae
69.	*Calidea* sp.	Scutelleridae
70.	*Chrysocoris stollii* (Wolff,1801)	Scutelleridae
71.	*Nezara viridula* (Linnaeus,1758)	Pentatomidae
72.	*Dolicoris* sp.	Pentatomidae
73.	*Rhaphidosoma* sp.	Reduviidae
74.	*Rhynocoris fuscipes* (Fabricius,1787).	Reduviidae
	Order: Hymenoptera	
75.	*Solenopsis invicta* (Buren,1972)	Formicidae
76.	*Solenopsis* sp.	Formicidae
77.	*Polyrhachis simplex* (Mayr 1862)	Formicidae

78.	*Camponotus compressus* (Fabricius,1787)	Formicidae
79.	*Camponotus sericeus* (Fabricius,1798)	Formicidae
80.	*Camponotus rufoglaucus* (Jerdon,1851)	Formicidae
81.	*Camponotus irritans* (Smith F., 1857)	Formicidae
82.	*Camponotus* sp.	Formicidae
83.	*Monomorium* sp.	Formicidae
84.	*Monomorium indicum* **(**Forel, 1902)	Formicidae
85.	*Monomorium minimum* (Buckley,1866)	Formicidae
86.	*Tetraponera rufonigra* (Jerdon,1851)	Formicidae
87.	*Tetraponera allaborans* (Walker,1859)	Formicidae
88.	*Ropalidia* sp.	Vespidae
89.	*Ropalidia marginata* (Lepeletier,1836)	Vespidae
90.	*Delta* sp.	Vespidae
91.	*Vespa affinis* (Linnaeus, 1764)	Vespidae
92.	*Chalybion bengalense* (Dahlbom,1845)	Sphecidae
93.	*Liris* sp.	Sphecidae
94.	*Sceliphron* sp**.**	Sphecidae
95.	*Apis indica* (Fabricius, 1798)	Apidae
96.	*Apis florea* (Fabricius,1787)	Apidae
97.	*Apis mellifera* (Linnaeus,1758)	Apidae
98.	*Encarsia formosa* (Gahan,1924)	Aphelinidae
99.	*Xylocopa* sp.	Xylocopidae
100.	*Scolia* sp.	Scoliidae
101.	*Brachymeria* sp.	Chalcididae
102.	*Stenobracon nicevillei* (Bingham,1901)	Braconidae
103.	*Callaspidia notata* (Fonscolombe,1832)	Figitidae
104.	*Halictus* sp.	Halictidae
105.	*Bethylus* sp.	Bethylidae
106.	*Campoletis* sp.	Ichneumonidae
	Order: Lepidoptera	
107.	*Danaus* sp.	Nymphalidae
108.	*Junonia almana* (Linnaeus, 1758)	Nymphalidae
109.	*Hypolimnas misippus* (Linnaeus, 1764)	Nymphalidae
110.	*Earias vittella* (Fabricius,1794)	Noctuidae

111.	*Helicoverpa armigera* (Hubner,1809)	Noctuidae
112.	*Eurema hecabe* (Linnaeus, 1758)	Pieridae
113.	*Catopsilia pyranthe* (Linnaeus,1758)	Pieridae
114.	*Pectinophora gossypiella* (Saunders,1844)	Gelechiidae
115.	*Scirpophaga incertulas* (Walker,1863)	Crambidae
116.	*Pelopidas mathias* (Fabricius,1798)	Hesperiidae
117.	*Papilio demoleus* (Linnaeus,1758)	Papilionidae k
	Order: Mantodea	
118.	*Mantis religiosa* (Linnaeus,1758)	Mantidae
119.	*Hierodula patellifera* (Serville,1839)	Mantidae
120.	*Humbertiella* sp.	Liturgusidae
121.	*Odontomantis planiceps*(Giglio-Tos,1913)	Hymenopodidae
	Order: Neuroptera	
122.	*Chrysoperla carnea* (Stephens,1836)	Chrysopidae
	Order: Odonata	
123.	*Pantala flavescens* (Fabricius,1798)	Libellulidae
124.	*Diplacodes trivialis* (Rambur,1842)	Libellulidae
125.	*Orthetrum sabina* (Drury,1770)	Libellulidae
126.	*Trithemis pallidinervis* (Kirby,1889)	Libellulidae
127.	*Urothemis signata* (Rambur,1842)	Libellulidae
128.	*Crocothemis servilia* (Drury,1770)	Libellulidae
129.	*Pseudagrion rubriceps* (Selys,1876)	Coenagrionidae
130.	*Ischnura aurora* (Brauer,1865)	Coenagrionidae
131.	*Coenagrion puella* (Linnaeus,1758)	Coenagriidae
	Order: Orthoptera	
132.	*Anacridium* sp.	Acrididae
133.	*Trilophidia annulata* (Thunberg,1815)	Acrididae
134.	*Spathosternum prasiniferum* (Walker,1871)	Acrididae
135.	*Aiolopus* sp.	Acrididae
136.	*Diabolocatantops pinguis* (Stål,1861)	Acrididae
137.	*Chrotogonus* sp.	Acrididae
138.	*Chrotogonus oxypterus* (Blanchard,1836)	Acrididae
139.	*Acrida exaltata* (Walker,1859)	Acrididae
140.	*Acrida* sp.	Acrididae

141.	*Oxya hyla hyla* (Serville,1831)	Acrididae
142.	*Cyrtacanthacris tatarica* (Linnaeus,1758)	Acrididae
143.	*Poecilocerus pictus* (Fabricius,1775)	Pyrgomorphidae
144.	*Atractomorpha crenulata* (Fabricius,1793)	Pyrgomorphidae
145.	*Atractomorpha* sp.	Pyrgomorphidae
146.	*Neorthacris simulans* (Bolívar, 1902)	Pyrgomorphidae
147.	*Gryllus* sp.	Gryllidae
148.	*Tetrix* sp.	Tetrigidae

4.5.2 Indices of distribution and diversity in insects occupying Nanguneri cotton agro-system

Shannon diversity (H') in Nanguneri taluk cotton agro-ecosystem during the study period February to September 2015 and February to September 2016 varied between 0.96 - 1.492 and 0.947-1.44 respectively (Table 20 and 21). It was higher in month of June and July (H'= 1.492 and 1.44), followed by in month of July and June (H'= 1.417 and 1.407), month of May and August (H'= 1.411 and 1.378), month of March and April (H'= 1.373 and 1.361). H' was Less in month of February (H'= 0.96 and 0.947).

The Shannon J'(evenness J') of insect had a range between 0.487 to 0.648. This was high in month of June and July (J = 0.648 and 0.625), less in month of February (J = 0.493 and 0.487). Hill's Number H0 (Species richness) was in the range of 20-131, highest in month of July and least in month of February. The Hill's Number H1 (abundance %) of insect ranged between 5.659% – 15.6%. Similarly Berger-Parker Dominance(d%) varied between 42.433% and 80.906%, which was high in month of July (80.906% and 79.565%) and less in month of February (45.377% and 42.433%).

Table 20. Indices of distribution and diversity in insects occupying in Nanguneri cotton agro- system during February 2015 to September 2015

Indices	Pre mature plants			Mature plants			Old plants	
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Shannon Diversity H'	0.96	1.373	1.287	1.411	1.492	1.417	1.205	1.172
Shannon J' (Evenness J')	0.493	0.66	0.559	0.613	0.648	0.615	0.523	0.509
Berger-Parker Dominance (d%)	45.377	46.043	59.572	65.005	72.976	80.906	79.703	71.963
Hill's Number H0 (Species Richness)	20	47	59	84	124	131	114	86
Hill's Number H1(Abundance %)	6.815	9.915	9.502	12.942	15.6	13.2	11.389	8.489

Table 21. Indices of distribution and diversity in insects occupying in Nanguneri cotton agro-system during February 2016 to September 2016

Indices	Pre mature plants			Mature plants			Old plants	
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Shannon Diversity H'	0.947	1.245	1.361	1.347	1.407	1.44	1.378	1.097
Shannon J' (Evenness J')	0.487	0.599	0.591	0.585	0.611	0.625	0.598	0.476
Berger-Parker Dominance (d%)	42.433	45.821	48.723	53.072	63.94	79.569	75.137	68.702
Hill's Number H0 (Species Richness)	16	40	51	75	114	120	109	83
Hill's Number H1(Abundance %)	5.659	8.691	10.281	10.067	10.978	11.521	10.534	7.024

4.6 Species Composition in Nanguneri Cotton Agroecosystem

4.6.1 Order Hemiptera (Plate 7A-H)

Insects under order Hemiptera were placed in two suborders Homoptera and Heteroptera. Seven species belonged to seven genera and five families of sub order Homoptera were collected in this ecosystem. *Bemisia tabaci* and *Aleyrodicus dispersus* represented Family Aleyrodidae. Family Membracidae identified two species viz., *Leptocentrus* sp. and *Oxyrachis tarandus, Amrasca biguttula biguttula* represented family Cicadellidae and *Aphis gossypii* represented family Aphididae. *Phenacoccus solenopsis* came under family Pseudococcidae.

In sub order Heteroptera a total number of twenty three species belonging to nineteen genera and nine families were collected. Family Pyrrhocoridae were identified three species namely *Dysdercus cingulatus, Dysdercus koenigii* and *Antilochus coquebertii.* Family Coreidae were recorded three species *Cletus* sp., *Oxycarenus hyalipennis* and *Leptocorisa acuta,* family Lygaeidae *Graptostethus servus, Dieuches* sp., *Lygaeus* sp. were collected. *Malacocoris* sp*., Pseudatomoscelis seriatus* and *Creontiodes biseratense* came under family Miridae, *Geocoris* sp., *Geocoris erythrocephalus* and *Geocoris punctipes* represented family Geocoridae, followed by Family Alydidae which recorded two species *Riptortus* sp. and *Riptortus pedestris.* Family Scutelleridae was represented two species *Calidea* sp. and *Chrysocoris stollii*. *Nezara viridula* and *Dolicoris* sp., was reported under family Pentatomidae. Under Family Reduviidae recorded two species *Rhaphidosoma* sp. and *Rhynocoris fuscipes*.

During the period of study order Hemiptera recorded highest population during July 2015and declined during August and September 2015. It showed the same trend during 2016, but the total population in slightly less (Figure 6). A remarkable increase in order Hemiptera could be observed during the fruiting season of the cotton plant.

4.6.2 Order Hymenoptera (Plate 8A-F)

Twenty nine species of Hymenoptera belonging to eighteen genera and twelve families were collected. Formicidae was the predominant family identified with thirteen species. They are *Solenopsis invicta, Solenopsis sp., Polyrhachis simplex, Camponotus compressus, Camponotus sericeus, Camponotus rufoglaucus, Camponotus irritans, Camponotus* sp., *Tetraponera allaborans, Monomorium* sp., *Monomorium indicum, Monomorium minimum* and *Tetraponera rufonigra.* This was followed by family Vespidae with four species namely *Ropalidia* sp., *Ropalidia marginata, Delta* sp. and *Vespa affinis,* Sphecidae were identified three species namely *Chalybion bengalense*, *Liris* sp. and *Sceliphron* sp**.,** *Apis indica, Apis florea* and *Apis mellifera* represented family Apidae*., Encarsia formosa* belonged to family Aphelinidae, *Xylocopa* sp. represented family Xylocopidae and *Scolia* sp. represented family Scoliidae. *Brachymeria* sp. was the only representative of family Chalcididae. *Stenobracon nicevillei* was a single species under family Braconidae, *Callaspidia notata* represented family Figitidae. Family Halictidae, Ichneumonidae and Bethylidae were the least represented families with one species.

Graphical representation of the population of order Hymenoptera was given in figure 7 Analysis of the graph showed a steady increase in the population during both the periods of survey upto July and then dwindled gradually.

4.6.3 Order Coleoptera (Plate 9A-G)

Recorded Twenty seven species from twenty two genera and twelve families were collected from in Nanguneri cotton Agroecosystem. Coccinellidae was the predominant family with eight species are *Brumoides suturalis, Rodolia cardinalis, Rodolia fumida, Cheilomenes sexmaculatus, Cheilomenes propinqua*, *Micraspis* *discolor*, *Coccinella transversalis* and *Coccinella* sp., followed by Curculionidae with three species *Myllocerus discolor, Myllocerus undecimpustulatus* and *Rhynchophorus palmarum.* Family Chrysomelidae identified the following species *Raphidopalpa Foveicollis, Cryptocephalus* sp. And *Acanthoscelides* sp. Family Meloidae identified only two species which were *Mylabris indica* and *Mylabris pustulata.* Family Scarabaeidae with three species were recorded and represented by *Chiloloba acuta, Onthophagus* sp. and *Diplotaxis* sp., *Oxycetonia versicolor* belonged to Family Cetonidae and *Paederus fuscipes* belonged to family Staphilinidae. *Ophionea indica* represented family Carabidae, *Aspidomorpha Cassidinae* belonged to family Cassidinae and *Gonocephalum* sp. was the representative of family Tenebrionidae. *Aspidomorpha* sp. represented famiy Cassidinae, *Agriotes* sp. belonged to family Elateridae and *Anthrenus* sp. was the representative of family Dermestidae.

Coleopteran population was high in the month of May 2015 and almost the same in the succeeding months (figure 8). However down during August and September 2015. The same trend was observed during 2016 but the population was less, compared to 2015.

4.6.4 Order Diptera (Plate 10A-E)

Sixteen species from thirteen genera and ten families were recorded, Family Calliphoridae with four species were identified as *Chrysomya megacephala, Chrysomya* sp., *Calliphora* sp., and *Lucilia* sp., This to as followed by Muscidae with three species namely *Musca domestica, Musca sp*., and *Limnophora* sp., *Tabanus* sp. and *Tabanus striatus* represented family Tabanidae. *Philodicus* sp. belonged to Family Asilidae and *Hedriodiscus* sp. belonged to family Stratiomyidae, *Sarcophaga* sp. represented family Sarcophagidae and *Chironomus* sp. represented family

Chironomidae, *Condylostylus* sp. represented family Dolichopodidae. *Tachinid* sp. belonged family Tachinidae and *Eristalinus aequalis* represented family syrphidae.

An observed in figure 9 Dipteran population was the highest during September 2015. Since July 2015 Dipteran population increased gradually. A similar situation was noticed during the next year survey, however with less numbers.

4.6.5 Order Orthoptera (Plate 11A-E)

Seventeen species of Orthoptera from fourteen genera and four families were collected from the cotton field. Acrididae was the most highly distributed family with eleven species are *Anacridium* sp., *Trilophidia annulata, Spathosternum prasiniferum, Aiolopus* sp., *Diabolocatantops pinguis*, *Chrotogonus* sp., *Chrotogonus oxypterus, Acrida exaltata, Acrida* sp.,

Oxya hyla hyla and *Cyrtacanthacris tatarica* Family Pyrgomorphidae enumerated four species and they were *Poecilocerus pictus*, *Atractomorpha crenulata*, *Atractomorpha* sp. and *Neorthacris simulans*. *Gryllus* sp. represented family Gryllidae and *Tetrix* sp. represented family Tetrigidae. Figure 10 depicts the population of order Orthoptera which showed a peak in the month of June during 2015 and July 2016.

4.6.6 Order Odonata (Plate 12A and B)

Nine species of Odonata belonged to nine genera and three families were collected. Libellulidae was the predominant family with six species which were *Pantala flavescens, Diplacodes trivialis, Orthetrum sabina, Trithemis pallidinervis, Crocothemis servilia* and *Urothemis signata* followed by family Coenagrionidae with two species namely *Pseudagrion rubriceps* and *Ischnura aurora. Coenagrion puella* belonged to family Coenagriidae. Dragonfly population steadily increased from March to June during both years and then declined. But during September 2016 again the population increased (figure 11).

4.6.7 Order Lepidoptera (Plate 13A-E)

Eleven species of Lepidoptera were collected classified under eleven genera and seven families. Nymphalidae family with three species were recorded and they were *Danaus* sp., *Junonia almana and Hypolimnas misippus* followed by the families Noctuidae (*Earias vittella, Helicoverpa armigera)* and Pieridae(*Eurema hecabe, Catopsilia pyranthe*), *Pectinophora gossypiella* belonged to family Gelechiidae, *Scirpophaga incertulas* belonged to family Crambidae, *Pelopidas mathias* belonged to family Hesperiidae and *Papilio demoleus* belonged to family Papilionidae.

Insects grouped under order Lepidoptera enumerated a high population during June especially during the flowering seasons of the cotton Plant (figure 12). These was steep decline in the population after the month of June during the period of study.

4.6.8 Order Mantodea (Plate 14A and B)

Four species of Mantodea were collected and were grouped under three genera and three families. *Mantis religiosa and Hierodula patellifera* represented family Mantidae, while *Humbertiella* sp. represented family Liturgusidae. *Odontomantis planiceps* belonged to family Hymenopodidae. Smaller in numbers Mantodea reached a peak during the month of May (figure 13) However during 2016 ie. in the second year of survey the population fluctuated after May 2016.

4.6.9 Order Blattodea (Plate 14C)

Order Blattodea was represented by only one family viz., family Blattellidae with a single species *Blattella* sp. Figure 14 shown the population of Blattodea, which is high during September 2015 even though the numbers were very less.

4.6.10 Order Neuroptera (Plate 14D)

Order Neuroptera was represented by only one species *Chrysoperla carnea* belonged to family Chrysopidae. Figure 15 showed that this species was abundant during May and June 2015.

4.7 Similarity index

A cluster analysis using Bray-Curtis similarity was performed for all insects collected from Nanguneri taluk of Tirunelveli District from February 2015 to September 2015 and February 2016 to September 2016. The insects were averaged over the orders and similarity analyses were performed on all 28439 and 17368 insects from 10 orders collected over the entire sampling period. The study showed a similarity (%) among the 10 orders which varied from 0.2217-87.4096% and 0.2344-81.4458% (Table 22 and 23) respectively. The maximum similarity was between the orders Lepidoptera and Odonata (87.4096% and 81.4458%) and Lepidoptera and Orthoptera (86.0526%) and then between Odonata and Orthoptera (78.6517%-85.5709%). A similarity above 60% was observed among orders Diptera, Lepidoptera, Odonata, and Orthoptera. Minimum similarity was found between orders Blattodea and Hemiptera (0.2217% - 0.2344%).

From the cluster analysis the population structure could be considered homogeneous below a Bray – Curtis similarity of 50%. The cluster analysis revealed three distinct clusters or groupings (Figure 17 and 18) a Bray-Curtis similarity above 50% indicating homogeneity. Homogeneity however begins to break down above 50% leading to the formation of six clusters indicating high level of dissimilarity in distribution. The main clusters further break down above a Bray-curtis similarity of 70% into more or less four smaller groupings of more closely associated orders.

Table 22. Insect orders similarity matrix in 2015

Insect orders	Blattodea	Coleoptera	Diptera	Hemiptera	Hymenoptera	Lepidoptera	Mantodea	Neuroptera	Odonata	Orthoptera
Blattodea	*	3.6078	7.6667	0.2217	1.0088	13.1429	33.5766	42.2018	11.8863	10.0877
Coleoptera	*	*	58.2832	11.3932	43.2544	41.4186	16.6911	12.855	45.0495	51.3947
Diptera	*	*	*	5.4171	22.5655	65.708	32.9957	25.9427	68.6504	70.6931
Hemiptera	*	*	*	*	35.9181	3.1064	1.094	0.8264	3.4519	4.0928
Hymenoptera	*	*	*	*	*	13.4457	4.9022	3.7205	14.8541	17.4245
Lepidoptera	*	*	*	*	*	*	51.7007	41.6465	87.4096	86.0526
Mantodea	*	*	*	*	*	*	*	83	47.6987	41.6819
Neuroptera	*	*	*	*	*	*	*	*	38.2222	33.1407
Odonata	*	*	*	*	*	*	*	*	*	85.5709
Orthoptera	*	*	*	*	*	*	*	*	*	*

Table 23. Insect orders similarity matrix in 2016

Insect orders	Blattodea	Coleoptera	Diptera	Hemiptera	Hymenoptera	Lepidoptera	Mantodea	Neuroptera	Odonata	Orthoptera
Blattodea	*	2.9979	7.7778	0.2344	0.8431	12.7854	32.9412	51.8519	12.5	8.284
Coleoptera	*	*	49.763	14.318	43.5297	36.4444	14.329	8.3333	37.1681	52.09
Diptera	*	*	*	5.6366	18.9433	63.1579	34.0528	20.7254	70.8633	67.7612
Hemiptera	*	*	*	*	43.3653	3.3784	1.1831	0.6683	3.4594	5.2876
Hymenoptera	*	*	*	*	*	11.6743	4.2037	2.3902	11.942	17.8463
Lepidoptera	*	*	*	*	*	*	49.2754	32.6531	81.4458	77.5047
Mantodea	*	*	*	*	*	*	*	68.4685	50.5338	35.9494
Neuroptera	*	*	*	*	*	*	*	*	32	21.978
Odonata	*	*	*	*	*	*	*	*	*	78.6517
Orthoptera	*	*	*	*	*	*	*	*	*	*

Figure 17. Dendrogram of all insect orders Nanguneri taluk from February 2015 to September 2015

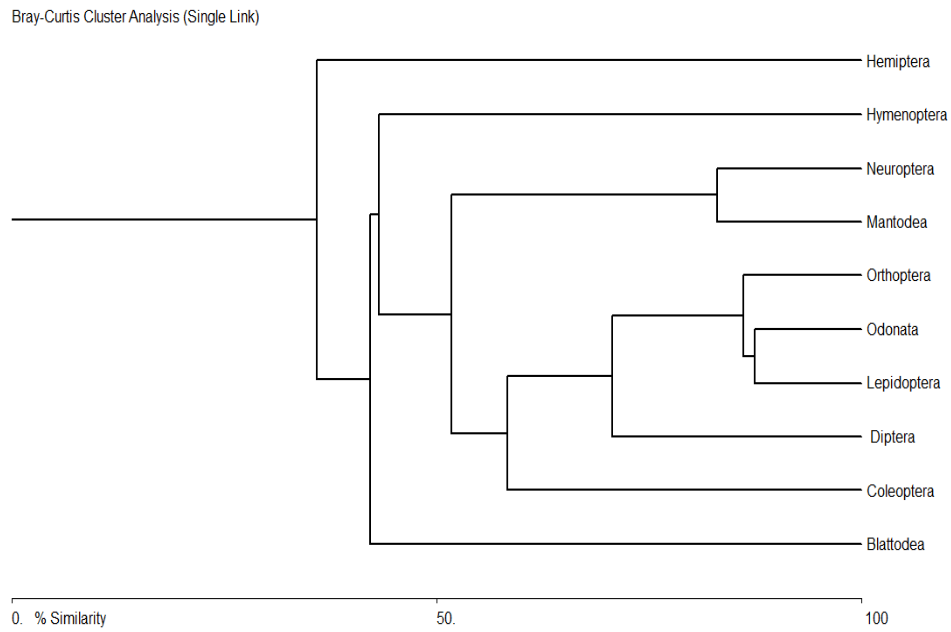
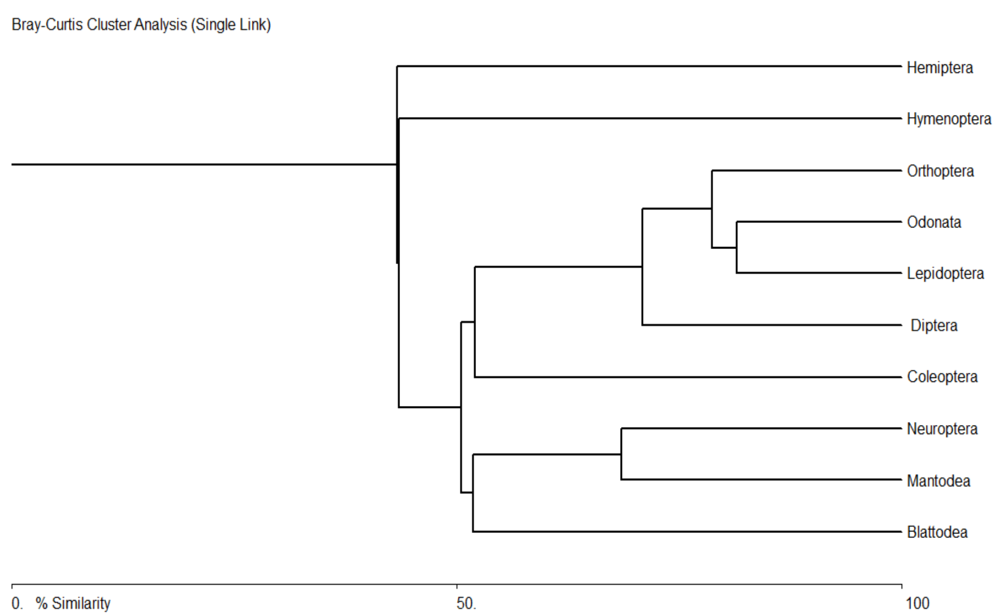


Figure 18. Dendrogram of all insect orders Nanguneri taluk from February 2016 to September 2016



4.8.1 Status of insect pests in cotton

Several insects attack cotton at various stages of growth. The list of insect pests observed in the present study are categorized as sucking pests, stainers, stem, leaf and foliar feeders and bollworms (Table 24).

4.8.1.1 Sucking Pests

Jassid (*Amrasca biguttula biguttula)* were identified throughout the entire life span of cotton crop. Jassids also referred, as leafhoppers are important sucking pests. The affected leaves curl downwards, turn yellowish, then to brownish before drying and shedding. Severe “hopper burn” was observed and stunt the young plants.

Aphid (*Aphis gossypii)* population was found from the third month of cotton crop, and appear sporadically. The nymphs and adults of aphid suck sap and excrete honey dew on leaves.

Whitefly (*Bemisia tabaci)* was identified from the fifth month of cotton crop and adults and nymphs suck sap from leaves and excrete honey dew on leaves which become sticky. Affected leaves and seeds cotton turn black due to development of sooty mould.

Mealy Bug especially (*Phenacoccus solenopsis)* was cottony white, fluffy, scale like insect, known to damage the plants by sucking the cell sap. Severe infestation resulted in stunted growth, premature leaf fall, incomplete opening of bolls and reduction in fibre quality. Honey dew secreted by nymphs and adults support growth of sooty mould on the plant.

Stink bug (*Nezara viridula*) was identified from the second month to entire life span of cotton crop which damaged buds and shoots. Seed bugs *(Graptostethus servus* and *Lygaeus* sp.) and Dusky cotton bug (*Oxycarenus hyalipennis*) began to occur from the fourth month till harvest of cotton crop. *Creontiodes biseratense* belonging family Miridae damage developing flower buds and tender bolls. Broad-headed bugs (*Riptortus* sp.) and Shield bugs *(Dolicoris* sp.) were identified from the third month of cotton crop and were found to damage leaves.

4.8.1.2 Stainers

Cotton Stainers are insects that feeds on developing and mature cotton seeds in the field. Common stainer bugs *Dysdercus cingulatus, Dysdercus koenigii* and *Oxycarenus hyalipennis*, both nymphs and adults fed on developing or mature seeds.

4.8.1.3 Stem, leaf, flower and foliar feeders

Myllocerus discolor and *Myllocerus undecimpustulatus* are commonly referred as grey or ash weevil which feds on leaves and its larvae fed on roots. Flower beetles (*Mylabris indica* and *Oxycetonia versicolor*) which feds on flower were observed from the third month cotton crop.

Chrotogonus trachypterus, Acrida exallata, Atractomorpha crenulata, *Acrida exaltata and Oxya hyla hyla* (order Orthoptera), they were identified throughout entire life span of cotton crop and damages seedlings, leaves.

4.8.1.4 Bollworms

Pectinophora gossypiella, Earias vittella and *Helicoverpa armigera* which was observed from the third and fourth month of cotton crop and were pests of buds, flowers and green bolls.

Table 24. List of insect pests of cotton field observed in Nanguneri taluk

Insect pest	Scientific name	Insect order	Damage
Sucking pests			
Jassids	*Amrasca biguttula biguttula*	Hemiptera	Leaves curl downwards, turn yellowish, then to brownish before drying and shedding, leading to hopper burn and stunts young plants
Aphids	*Aphis gossypii*	Hemiptera	Leaf crumpling and downward curling of leaves, deposits of honey dew on open bolls
Whiteflies	*Bemisia tabaci*	Hemiptera	Upward curling of leaves, lint contamination with honey dew and associated fungi,
Mealy bugs	*Phenacoccus solenopsis*	Hemiptera	Feeds on plant sap. Attach themselves to the plant and secrete a powdery wax layer.
Stink bugs	*Nezara viridula*	Hemiptera	Damages buds and shoots
Seed bugs	*Graptostethus servus*	Hemiptera	Damage seeds and open bolls
Seed bugs	*Lygaeus* sp.	Hemiptera	Damages seeds and open bolls
Mirids	*Creontiodes biseratense*	Hemiptera	Damages developing flower buds and tender bolls
Broad-headed bugs	*Riptortus* sp.	Hemiptera	Damages leaves
Shield bugs	*Dolicoris* sp.	Hemiptera	Damages leaves
Stainers			
Red cotton bugs	*Dysdercus cingulatus* and *Dysdercus koenigii*	Hemiptera	Feeds on developing and mature seeds, stain the lint to typical yellow colour, reddish nymphs seen in aggregations around developing and open bolls
Dusky cotton bugs	*Oxycarenus hyalipennis*	Hemiptera	Feeds on seeds, discolour the lint.

Stem, leaf, flower and foliar feeders			
Ash weevils	*Myllocerus discolor*	Coleoptera	Feeds on stem, leaf and foliages
Weevils	*Myllocerus undecimpustulatus*	Coleoptera	Feeds on stem, leaf and foliages
Beetles	*Mylabris indica*	Coleoptera	Feeds on flowers
Flower Beetles	*Oxycetonia versicolor*	Coleoptera	Feeds on flowers
Surface Grasshoppers	*Chrotogonus trachypterus*	Orthoptera	Feeds on Seedlings, leaves
Tobacco grasshoppers	*Atractomorpha crenulata*	Orthoptera	Damages Leaves
Desert locusts	*Acrida exaltata*	Orthoptera	Damages Leaves
Grasshoppers	*Oxya hyla hyla*	Orthoptera	Damages Leaves
Bollworms			
Spotted bollworms	*Earias insulana*	Lepidoptera	Affects floral buds, flowers, green bolls
Spiny bollworms	*Earias vittella*	Lepidoptera	Affects floral buds, flowers, green bolls
Cotton bollworms	*Helicoverpa armigera*	Lepidoptera	Affects leaves, green bolls, flowers

4.8.2 Beneficial insects

Beneficial insects in the cotton agroecosystems included pollinators, predators and parasitoids (Table 25).

4.8.2.1Pollinators

Pollinators were found during the flowering seasons of cotton plant especially in the months of April to August. The predominant pollinators identified were *Apis dorsata, Apis florae, Apis mellifera* and *Xylocopa* sp. of order Hymenoptera.

4.8.2.2 Predators

Chrysoperla carnea of order Neuroptera was recorded from the third month of cotton crop, and was found to control of sucking pests and bollworms. Their larvae were voracious predators of sucking pests and bollworms attacking them at various stages of their life cycle including egg, nymph and adult.

Coccinellids species such as *Menochilus sexmaculatus, Brumoides suturalis , Rodolia cardinalis*, *Rodolia fumida, Cheilomenes sexmaculatus, Cheilomenes propinqua, Micraspis discolor, Coccinella transversalis and Coccinella* sp. can be found throughout entire life span of cotton crop. Both larval and adult stages of ladybird beetles were beneficial as they prey upon aphids, mealy bugs and whiteflies. The eggs and nymphs of aphids were attacked, whereas nymphs and adults of mealy bugs were targeted. In case of whitefly nymphs were attacked. Rove beetle (*Paederus fuscipes)* fed on small insects found in the fifth month of cotton field.

Eristalinus aequalis(order Diptera)*, Paederus fuscipes*(order Coleoptera) *,Geocoris* sp, *Antilochus coquebertii* and *Rhynocoris fuscipes* (order Hemiptera)*, Vespa* sp, *Camponotus compressus* and *Camponotus sericeus* (order Hymenoptera)*, Pantala flavescens, Trithemis pallidinervis* and *Coenagrion puella*(order Odonata) and *Mantis religiosa* (order Mantodea) were found to attack cotton pests during the period of survey.

4.8.2.3 Parasitoids

Tachinid sp.(order Diptera), *Campoletis* sp. and *Encarsia Formosa*(order Hymenoptera) were found from the fourth month of cotton crop and these parasitoid species of flies and wasps attacked cotton pests, especially the lepidopteran larvae and whitefly nymphs.

Table 25. List of beneficial insects of cotton fields observed in Nanguneri taluk

Insect	Scientific name	Insect order	Nature of benefit
Pollinators			
Honey bees	*Apis dorsata*	Hymenoptera	Pollination of plants
	Apis florea	Hymenoptera	Pollination of plants
	Apis mellifera	Hymenoptera	Pollination of plants
Carpenter bees	*Xylocopa* sp.	Hymenoptera	Pollination of plants
Predators			
Lacewings	*Chrysoperla carnea*	Neuroptera	Attacks sucking pest and bollworms
Ladybird beetles	*Brumoides suturalis*	Coleoptera	Attacks sucking pest and bollworms
	Rodolia cardinalis	Coleoptera	Attacks aphids, jassids, mealy bug
	Rodolia fumida	Coleoptera	Attacks aphids, jassids
	Cheilomenes sexmaculatus	Coleoptera	Attacks sucking pest and bollworms
	Cheilomenes propinqua	Coleoptera	Attacks sucking pest and bollworms
	Micraspis discolor	Coleoptera	Attacks aphids, jassids
	Coccinella transversalis	Coleoptera	Attacks sucking pest and bollworms
	Coccinella sp.	Coleoptera	Attacks aphids, jassids
Hoverflies,or flower flies, or syrphid flies	*Eristalinus aequalis*	Diptera	Attacks aphids
Rove beetles	*Paederus fuscipes*	Coleoptera	Attacks small insects
Big eyed bugs	*Geocoris* sp.	Hemiptera	Attacks whitefly, bugs, bollworms
True bugs	*Antilochus coquebertii*	Hemiptera	Attacks many cotton pests
Assassin bugs	*Rhynocoris fuscipes*	Hemiptera	Attacks bollworms, sucking pest, *Mylabris indica*
Wasps	*Vespa* sp.	Hymenoptera	Attacks many cotton insects

Ants	*Camponotus compressus*	Hymenoptera	Attacks Jassids
Ants	*Camponotus sericeus*	Hymenoptera	Attacks Jassids
Dragonflies	*Pantala flavescens*	Odonata	Attacks small insects
Long-legged marsh gliders	*Trithemis pallidinervis*	Odonata	Attacks small insects
Damselflies	*Coenagrion puella*	Odonata	Small insects
Mantis	*Mantis religiosa*	Mantodea	Caterpillars other insects
Parasitoids			
Flies	*Tachinid* sp.	Diptera	Parasitise bollworms eggs and larva
Wasps	*Campoletis* sp.	Hymenoptera	Parasitise bollworms eggs and larva
Wasps	*Encarsia formosa*	Hymenoptera	Parasitise whitefly nymphs

CHAPTER 5
DISCUSSION

Agroecosystem are unstable ecosystems (Coman and Rosca 2013); they have advantages, disadvantages and much spatial and temporal heterogeneity, which are largely determined by anthropogenic activities (Marquez Hernandez *et al*., 2014). Much is known about how species are affected by heterogeneity and how they persist in agricultural systems, being an important part of biodiversity (Hughes *et al*., 2002 and Zhang *et al*., 2007).

Taxonomic identification of insects in diversity studies is through parataxonomy and/or morphospecies (Krell 2004; Majka and Bondrup 2006). The biodiversity of an ecosystem is known through biological inventory, including entomofaunistics. However only a few diversity studies consider insects (Yi *et al*., 2011), although they are indespensable tools in conservation and monitoring of ecosystems (Lawton *et al.,* 1998, Losey and Vaughan 2006). According to Perez *et al*., (2011), studies on entomofaunistic diversity in agroecosystems are rare.

5.1 Population Dynamics

In the present study 10 insect orders with 68 families, 123 genera, 148 species of insects were observed. According to Hargreaves, (1948), the cotton ecosystems provide home to about 1326 species of insects from showing to maturity in different cotton growing area of the world. Our results also agree with the findings of Khan and Rao, (1960), who claims that 166 species are present on cotton crop in India. According to Bal Harid and Dhawan (2009), 134 species of insects recorded arthropods on the cotton crop. There are 137 species in 32 families and 10 orders of insects in the cotton agroecosystem in India (Sabesh 2007, MEF 2011). Bohmfalk *et al*.,(2011), mentioned that 50 insect pests, beneficials, predators and parasites are associated with cotton.

In the present investigation insect population was found to be the highest during the months of June, July and August of 2015 and 2016 especially when the plants were mature. It is noteworthy to say that mature cotton plants during flowering and fruiting stages are rich in its nutritious plant sap, which attracts many species of insects. Dwomoh *et al*., (2008) making survey on the insect species associated with cashew also reported a similar observation.

In all the three sites i.e., Kunthankulam, Moolaikaraipatti and Chinthamani the insect population was more in Kunthankulam during February 2015 to September 2015 and February 2016 to September 2016. This may be due to the Habitat influence. Among the three sites Kunthankulam is rich in its water resource and a clayey soil texture. Moolaikaraipatti does not possess adequate water resource and the soil texture is different from Kunthankulam, Chinthamani has a loamy red soil and semiarid in nature. Hence the influence of habitat and environment may play a role in the distribution of insects. Moreover insects serve as indicators of environment and indicator of the ecological well being of an ecosystem (Buchs, 2003).

5.2 Insect Diversity

Entomofaunistic survey of the cotton crop in three different sites of Nanguneri taluk of Tirunelveli District revealed that the composition of insect fauna varied, however with age and growth of cotton plants. Fewer insect species were encountered on young immature plants than mature and grown up plants. Agboton *et al*., (2014) also possessed the same opinion who had studied the insect fauna associated with *Anacardium occidentale* in Benin, West Africa.

Totally 10 insect orders were reported from the present study. They were order Hemiptera, Hymenoptera, Coleoptera, Diptera, Lepidoptera, Orthoptera, Odonata, Mantodea, Neuroptera and Blattodea. The predominant insect orders were found to be order Hemiptera, order Hymenoptera and order Coleoptera. Insects belonging to order Diptera, Lepidoptera, Orthoptera and Odonata came next. Our results agrees with the report of Marquez-Hernandez *et al*., (2014) who have studied the entomofaunistic diversity in a transgenic cotton (*Gossypium hirsutum* L.) agroecosystem in Coahuila, Mexico. The data were similar to the insects reported by Sabesh (2007) and MEF (2011) who found 10 orders of insects in cotton, but the number of orders exceeded that was reported by Frank and Slosser (1996). Agboton *et al*.,(2014) working on the insect diversity of Cashew tree have reported that the insects under the three most important orders Coleoptera, Hemiptera and Hymenoptera were predominant. Further it could be proper to report that, insects being positively phototrophic, use of light traps for insect catches attracts mostly coleopterans, hemipteran, hymenopteran and lepidopteran insects. Our results also agree with the earlier reports of Dadmal and Suvarnakhadakkar (2014) and Ramamurthy *et al*., (2010) who reported that Coleopterans dominate the insect catches followed by Hemipterans, Hymenopterans and Lepidopterans.

A comparison of the three sites viz., Kunthankulam, Moolakaraipatti and Chinthamani regarding the insect population revealed that insects belonging to order Hemiptera were high with 71-75%, 68-75% and 65-68% respectively. Similarly Hymenoptera represented 15-17%, 13-19% and 20-23% in the three sites. Coleoptera ranked third with 4-6% and 5%. These differences may be attributed to the environmental influence. Kunthankulam being fertile harbours a high population of piercing and sucking insects which mostly come under order Hemiptera.

Order Hemiptera had the highest number of insects and abundance due to the infestation of aphids and mealy bugs which was evaluated through grading system. This could accompolish richness and abundance of hemipteran insects. As there was a severe infestation towards the flowering and fruiting seasons, sampling was found to be difficult and grading system was applied.

However insects coming under order Hymenoptera were high in Chinthamani due the ant population due to the semi arid environment. Tropical countryside habitats can retain remarkably diverse arthropod assemblages (Perfecto *et al*., 1996; Kitching *et al.,* 2000 and Ricketts *et al*., 2001). According to Didham *et al*., (1996), Chapin *et al*., (2000) and Sala *et al.,* (2000) ecosystem function and services can be related to changes in biodiversity. Hence environmental diversification of the crop habitats may provide difference in insect diversity.

5.3 Species Composition

Field survey conducted during the two years of study showed differences in the three cotton agroecosystems. Cotton field of Kunthankulam, Moolaikaraipatti and Chinthamani recorded a total of 116, 106 and 83 species of insects respectively. These findings show that it may be due to the habitat influence on insect diversity. Among the three study sites Kunthankulam is rich in its water resources surrounded by many ponds and soil being highly fertile and posses a composition of 116 species of insects. Moolaikaraipatti unlike Kunthankulam does not possess much water resources and remain dry (106 species). But Chinthamani has a semi arid habitat with dry weather and red soil which harbours a lesser number of 83 insect species. It is understood that environment and habitat plays a major role in the distribution of insects. Changes in biodiversity is caused by species habitat affiliations (Hughes *et al*., 2002), Goehring *et* *al*., (2002) demonstrated that, Changes in community composition mainly depends on the habitat types investigated. According to Daily (1999) and (2001) and Rosenzweig (1999) conservation biologists has to understand the capacity of countryside habitats to support biodiversity and conversely, the capacity of different taxa to exploit such habitats. Some arthropod taxa show species-area effects in native habitats (Daily and Ehrlich 1995; Richardson *et al.,* 1999).

In all the cotton fields insects under order Hemiptera were abundant represented by 12 to 14 families, followed by Hymenoptera with 6 to 11 families and order Coleoptera with 9 to 12 families. There were variation in the taxonomic composition which again may be due to habitat and anthopogenic influence. This could be demonstrated by the fact that only 9 families represented order coleopteran in Kunthankulam where as in semiarid zones of Moolaikaraipatti and Chinthamani had 12 and 10 families respectively. Similar changes in other insect orders are evident due to habitat influence. Certain insects may be native, while other may be phytophagous on cotton. Further these variations might be due to sampling method, weather, adjacent crops and production system (Marquez-Hernandez 2014). Sosa *et al*., (2011) found families Cicadellidae and Lygaeidae and Anthocoridae of order Hemiptera and also the families Carabidae, Chrysomellidae, Coccinelidae, Curculionidae, Elateridae, Melyridae and Scarabaeidae of the order Coleoptera. In the present study also all the above families were recorded. The present study also agrees with the observation of Diaz and Zamora (2001) who mentioned family curculionidae of the order coleoptera.

In Lepidoptera, Sosa *et al*., (2011) reported the family Noctuiidae. In Orthoptera Sosa *et al*., (2011) found the families Acrididae and Gryllidae. The family Chrysopidae of Neuroptera was mentioned by Sosa and Vitti (2003), Lizarraga (2008) and Najera and Souza (2010). In order Hymenoptera Sosa *et al*., (2011) reported the families

Chalcidoidea and formicidae. Najera and Souza (2010) mentioned the family Braconidae. Perez *et al*.,(2012) found the family Apidae. Cabrera *et al*.,(2011) reported family Formicidae. Malerbo and Halak (2011) mentioned families Apidae and Vespidae. The present findings are in agreement with the above results. Sosa *et al*., (2011) have claimed that order Diptera was the second most abundant in cotton. This differed from the present finding.

5.4 Climatic factors and Insect diversity

An analysis of the data of insect collection in the three areas of cotton agroecosystem revealed that climatic factors such as rainfall, temperature and relative humidity greatly influence the insect population and diversity. Invariably in all the sites of Nanguneri taluk, the insect population remained high from February 2015 to September 2015 then February 2016 to September 2016. An observation of meteorological parameters during the study period revealed that even though the temperature remained uniform throughout the two years, remarkable variation in rainfall could be observed. The mean rainfall during February 2015 to September 2015 that is during the cultivation period of cotton was 52.1mm whereas it was only 2.3mm in 2016. This drastic difference has influenced the insect population and diversity which could be evidenced from the above results. Similarly the relative humidity was 64.9% in 2015 and 58.6% in 2016. Thus weather parameters are able to influence the entomofaunistic diversity greatly. Michael raja *et al*., (2011) reported that rainfall and humidity were relatively normal during summer and the population density decreased due to the increased temperature and wind velocity Edwin(1997) reported that high temperature, low humidity and poor rainfall caused a general reduction of Hemipterans. The present observation agrees with the above results. Rainfall is a crucial factor for the increase of the insect population followed by temperature (Puttannavar *et al*., 2005). Changluwang *et al*., (2000) reported most species of ants have a strong ability to adapt to weather changes by modifying their nest and behavior. This report agrees with our results as in July 2016 when the rainfall was 12.4mm Hymenopteran population increased presumably due to the ant population captured through pit fall traps. Vijayababu *et al*., (2016) have reported climate change will fundamentally alter the agro-ecosystem. Leading to changes in insect diversity and population levels. The abundance of insect pests depends on season length, rainfall, temperature, surrounding vegetation and agronomic practices (Pimentel and Wheeler 1973; Wilson 1994). According to Didham *et al.,* (1996) and Laurance and Bierregaard (1997) microclimatic changes and other consequences of fragmentation can impact dynamics of invertebrate communities of remnant forest fragments.

5.5 Diversity Indices

Shannon Index of diversity is considered to be the most complete measure of diversity. Because it takes into account both the number of species and the abundance of each species during the study in Nanguneri taluk cotton field the Shannon index of diversity ranged from 0.947 to 1.492. The same trend was observed in the succeeding year and in other study areas also, which corroborates with the total insect population and individual orders. Similar reports were revealed by Usha and Vimala (2015).

Dominance index the measure of dominance by any one species, that is if any species is found to be exponentially abundant when compared to the others in a community, then such species can be called dominant and such a community may return high dominance index (near to 1). In the present investigation highest dominance index (D) was observed in the months of July 2015 and 2016 (0.67 and 0.649). The dominance index (D) was less in the beginning in premature plants in the months of February, march and April, and increased maximum during maturity and declined in older plants. This would probably due to the fact that some insects appear in a few months in each year and the life cycle is regulated by diapause. Based on day lengths and Humidity (Wolda 1983), which reviewing seasonal patterns of insect abundance observed that seasonal peaks are more commonly found in the tropics. Similar results in the case of herbivorous insects were obtained in a study conducted to estimate the species composition and seasonal abundance of carabidae in a forest partly surrounded by paddy fields (Yahiro 1990). The reason for such variation could be several including changes in weather and growth stages of cotton.

Evenness which takes into account the distribution of species and their numbers across different stages of growth of cotton plant have shown figures ranging from 0.487 to 0.648 (highest value is 1). This indicates that no species was dominant in terms of abundance. Our results agrees with the findings of Usha and Vimala (2015) who have studied the insect diversity of selected area in Wadakkanchery (Thrissur, Kerala).

Price (1984) revealed that the reason of the decline in diversity was due to the increased dominance of one species. However Poole (1974) reported that the diversity indices to be strongly affected by the abundances of the middle species of a community rather than by the common or rare species. It was reported that the increased diversity led to the increased stability (Poole 1974; Risch *et al*., 1983). Similar report was proposed by Ohnmar Khaing *et al*., (2002) who have studied the species diversity of cotton insect pests. Kuukyi and Wiafe (2016) have reported that density and diversity of insects during the flowering season differed from fruiting season in cashew. This supports the hypothesis that insect diversity in different stages of growth of cotton plant are not the same.

From the above analysis we can conclude that even though the insect population and taxonomic groups were high in mature plants especially during flowering and fruiting the value ranges of alpha diversity indices did not change much. The month of July of 2015 and 2016 stood with maximum diversity.

5.6 Similarity index

From the cluster analysis the insect population of different orders had a fairly similar species distribution for the two years of survey. The dominance of Hemiptera followed by Hymenoptera, Coleoptera and Diptera at the study areas of Nanguneri taluk may explain the similarity. It is interesting to note that Lepidoptera, Odonata and Orthoptera cluster together around 80 to 90% indicating high level of similarity in distribution. Similar reports were given by Rosina Kyeremater *et al*., (2014) working on Insect Diversity of the Muni-Pomadze Ramsar site in Ghana. According to Hart and Horwitz(1991), the habitat heterogeneity hypothesis simply predicts that more arthropods species will occur where different forms and species of plants provide greater structural heterogeneity in the vegetation. Richness and Diversity may depend on resource availability and larval host plants, behavioral traits and interaction with other species (Pinheiro and Ortiz 1992).

5.7 Status of insect pests and beneficial Insects in cotton

Our results correspond to the earlier reports given by many authors. MEF (2011) have declared sucking pests, bollworm, stem and foliar feeders and stainers as the key pests of cotton Shitole and Patel (2010) have considered that spotted bollworm, *Earia vitella* as one of the major pest of cotton, especially when flower buds arise and formation of bolls. Vikas Jindal *et al*., (2010) have studied the seasonal dynamics of key pests on cotton in Punjab and our results also agrees with these findings. Bhute *et* *al*., (2012) have conceded that sucking pests also attack BT cotton. Dahya *et al*., (2013) studying on the influence of abiotic factors on the distribution of leafhoppers and white fly on cotton plants reported that they dominate the cotton agroecosystem. Further our findings agree with the report of Ian Kaplan and Eubanks (2002), Ohnmar Khaing *et al*., (2002) and Bal Harit and Dhawan (2009). The incidence of pollinators, predators and parasitoids in the present study are in accordance with the previous report of Arshad *et al*., (2015).

SUMMARY AND CONCLUSION

Cotton is a major fibre crop of global importance and India has emerged as the second largest producer of cotton. Tamil Nadu is one among the major states that grows cotton in India. Being commercially important, cultivation of cotton is taken up by even small farmers and further natural growth of cotton can be taken up during hot or dry weather. In the present study, entomofaunistic survey of the cotton agroecosystems of Nanguneri taluk of Tirunelveli district was undertaken with a view to identify the insect diversity during the growth stages of cotton plant.

Field survey conducted in Kunthankulam, Moolaikaraipatti and Chinthamani of Nanguneri taluk from February 2015 to September 2015 and February 2016 to September 2016 revealed a total insect population of 28439 and 17368 respectively representing 10 insect orders, 68 families, 123 genera, 148 species of insects. Order Hemiptera recorded highest percentage (71%), followed by order Hymenoptera (17%) and order Coleoptera (5%). Species Richness is high in the months of July and August due to flowering and fruiting seasons of the cotton plants. Abundance of insects in these months are mainly due to insects belonging to order Hemiptera. However the alpha diversity do not change much.

Since weather parameters such as temperature rainfall and humidity play a role in the distribution of insects they were considered for the present survey. Eventhough not much variation was recorded with regard to temperature, rainfall was high during 2015 (52.1mm) than 2016 (2.3mm). This drastic difference had influenced the insect population and diversity.

From the cluster analysis the population structure could be considered homogeneous below a Bray-Curtis similarity of 50%. Cluster analysis revealed three distinct clusters above 50% indicating homogeneity. Homogeneity however broke down above 50% leading to the formation of six clusters indicating high level of dissimilarity in distribution throughout the life span of cotton plant.

During the course of investigation and survey, it was found that some insect species were common and abundant at various seasons in the cotton fields. They mostly belonged to order Hemiptera, Lepidoptera, Coleoptera and Orthoptera and remained in this agroecosystems persistently and have attained the pest status and cause major economic loss. The study has recorded 24 insect pests of which 16 species were common and most abundant. Apart from these few beneficial insects in the form pollinators, predators and parasitoids were also identified.

To conclude the present investigation provides a comprehensive inventory of the entomofaunistic diversity of cotton plant in Nanguneri taluk of Tirunelveli District. Survey for a period of eight months throughout the life span of cotton plant reveals the species diversity, their abundance and dominance at various stages of growth of cotton. The study gives a clear picture of insect diversity which is influenced by climatic factors such as temperature, rainfall and humidity and also the habitat. Further it may also be influenced by anthropogenic activities and agronomic practices in the cotton agroecosystem. Cotton cultivation encounters with diverse insect species from early stages of growth till harvest season. From this study we could recognize the particular species that is predominant during a particular period, some of which may be natural inhabitants monophagous pests, pollinators, predators and parasitoids. As a result, we can identify the potential pests of cotton and their seasonal abundance and provide adequate information which helps to predict efficient management strategies that can be adopted by cotton growers of Nanguneri taluk of Tirunelveli district.

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1. D. Siva Kumar & B. Xavier Innocent, 2017, “Araneae (Spiders) Fauna of cotton Agroecosystem in Nanguneri, Tirunelveli, Tamil Nadu”, World Journal of Pharmaceutical and life Sciences, vol.3, no.9, pp. 155-158, ISSN: 2454-2229. IF – 4.223.

2. M. Eathel Poline, D. Siva Kumar, J. Babila Jasmine & B. Xavier Innocent, 2015, “Histological changes brought by *Aeromonas hydrophila* on some cells of spotted murrel, *Channa punctatus* (Bloch)”, *World International Journal for Life Sciences and Educational Research*, Vol. 1, no.1, pp. 1 - 6, E-ISSN : 2321-1229; P-ISSN : 2321-1180.