POPULATION ECOLOGY OF COCONUT BLACK HEADED CATERPILLAR *Opisina arenosella* WALKER (LEPIDOPTERA : XYLORICTIDAE)

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Dedicated to the
Sweet Memory of
My 36 day old Son

DIVISION OF ENTOMOLOGY

UNIVERSITY OF AGRICULTURAL SCIENCES

BANGALORE

CERTIFICATE

This is to certify that the thesis entitled **"POPULATION ECOLOGY OF COCONUT BLACK HEADED CATERPILLAR** *Opisina arenosella* **WALKER (LEPIDOPTERA : XYLORICTIDAE)"** submitted by **Mrs. N. APPAJI PUSHPALATHA** for the degree of **DOCTOR OF PHILOSOPHY** in **AGRICULTURAL ENTOMOLOGY** of the University of Agricultural Sciences, Bangalore is a record of research work done by her during the period of her study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

(G.K. VEERESH)

Bangalore
September , 1991

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INTRODUCTION

I INTRODUCTION

Right from the nursery stage the Coconut palm (Cocos nucifera L.) is attacked by more than 110 insect pests (Lever, 1969).

The Black headed caterpillar, Opisina arenosella Wlk., (= Nephantis serinopa Meyr.,) is one of the major pests of coconut in India, Sri Lanka and Burma. The earliest report of its occurrence as pest was from the Batticaloa district of Ceylon (Green, 1906). In India, it was first recorded in Guntur district of Andhra Pradesh in 1909 (Rao et al., 1948). The damage ranges from 25 to 75 per cent as reported from Kerala (Lal, 1968) and upto 82 per cent reported from Sri Lanka (Dharmaraju, 1963).

The pest also attacks other palms like the palmyra palm (Borassus flabellifer), the talipot palm (Corypha unbraculifera), the toddy palm (Phoenix sylvestris) and some ornamental palms (Mohamed et al., 1982a). In addition the pest was observed to attack banana, grown both as an inter crop with coconut and as a monocrop, with symptoms similar to that on coconut leaves (Manjunath, 1985).

The larva (Pl.1) of O. arenosella feeds on the green tissues of undersurface of the leaves and constructs galleries of silk and excreta and finally pupates (Pl.2) within it. Due to severe feeding on green tissues, the leaflets dry up and give a burnt appearance (Pl.3), leading to reduction in nut production. In cases of severe infestation, the caterpillars feed on the green matter of the husk causing premature drying of nuts and nut drop.

Attempts were made to control this pest by various methods, the earliest being removal and burning of severely infested leaflets and fronds. Later, chemical methods like spraying, stem injection (Nadarajan and ChannaBasavanna, 1981) and root feeding of insecticides, (Pushpalatha, 1986) were advocated.

O. arenosella is known to have a number of natural enemies, including Apanteles taragamae Vier.(Pl.4), Goniozus nephantidis Muesebeck and Parena nigrolineata Chaud (Pl.5) (Dharmaraju, 1962). Nadarajan (1977) has listed 15 parasitoids and six predators. Biological control of this pest was attempted as early in 1920's in India (Ramachandran et al., 1979).

Of the numerous parasitoids, Apanteles taragamae is a predominent, internal parasitoid of early instar larvae. They are solitary parasitoids attacking first and second instar larvae. It is distributed in the coastal regions of Tamil Nadu, Andhra Pradesh and Orissa. In Karnataka it was reported from Mangalore for the first time in 1922 (Ramachandra Rao, 1924).

Parena nigrolineata is one of the commonly occurring predators of O. arenosella. The eggs are laid inside the galleries and the grubs continue to live in the galleries and feed on the caterpillar. The grubs after a month and half pupate within the gallery for 6 to 7 days. Although the Grubs feed on a large number of O. arenosella (Gulagannavar, 1984), its population fluctuation in relation to its host, biotic and abiotic factors in nature has not been studied.

The present study was mainly intended to determine (i) the spatial distribution and population fluctuation of O. arenosella during the year in relation to abiotic and biotic environmental factors, (ii) to standardise the sampling technique, and (iii) to know the Interspecific associations among O. arenosella, A. taragamae and P. nigrolineata in a coconut ecosystem.

PLATE 1. Larva of Opisina arenosella Wlk feeding on a leaflet

PLATE 2. Exposed pupa of Opisina arenosella Wlk

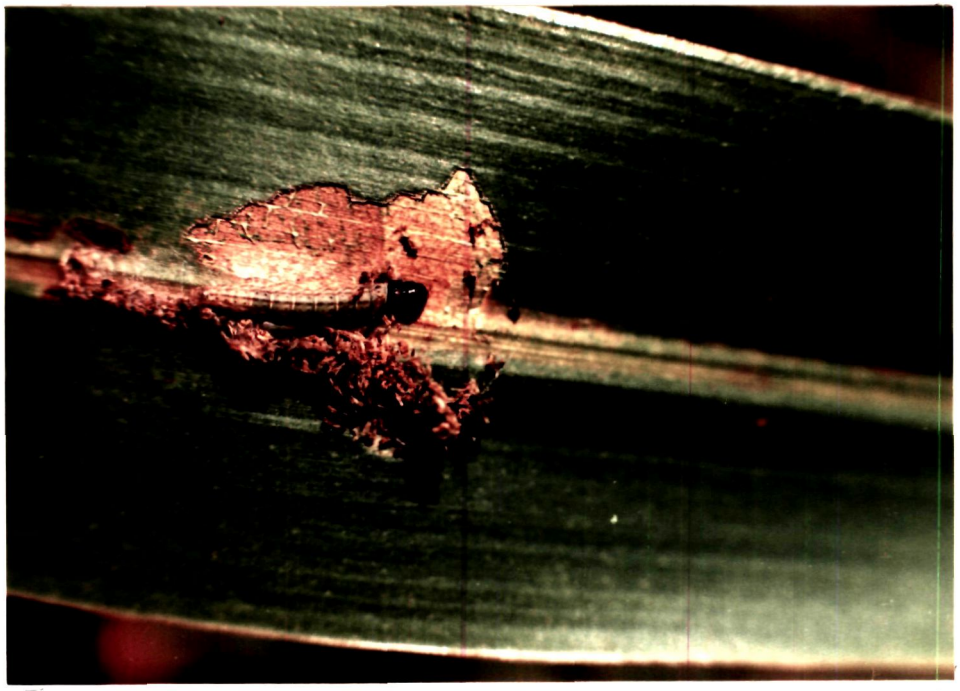
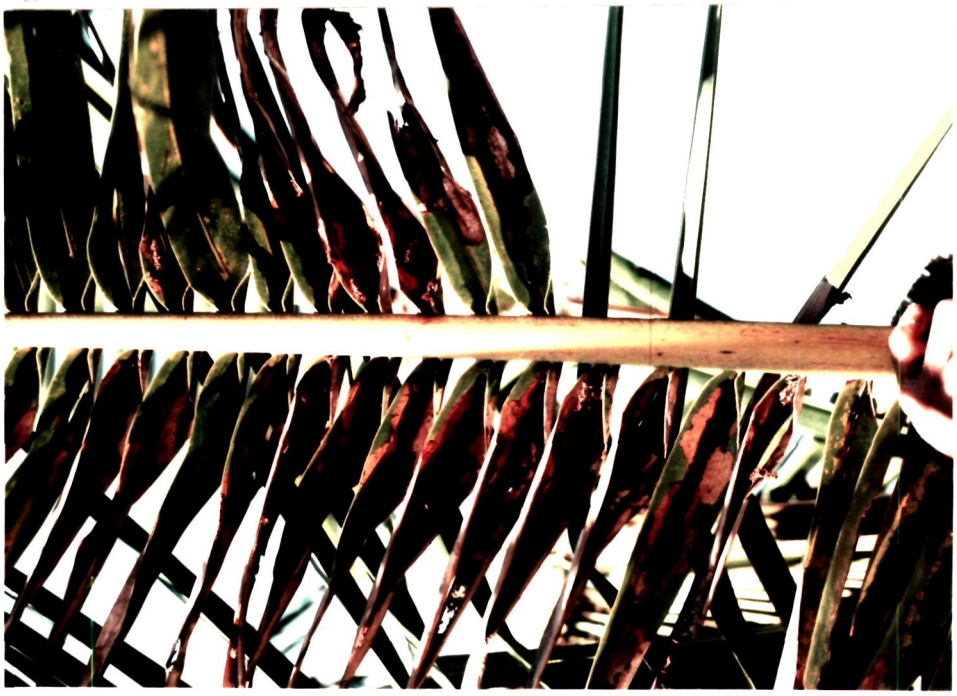


PLATE 3. Severely infested leaflets

PLATE 4. Adult ♀ and ♂ of Apanteles taragamae Vier



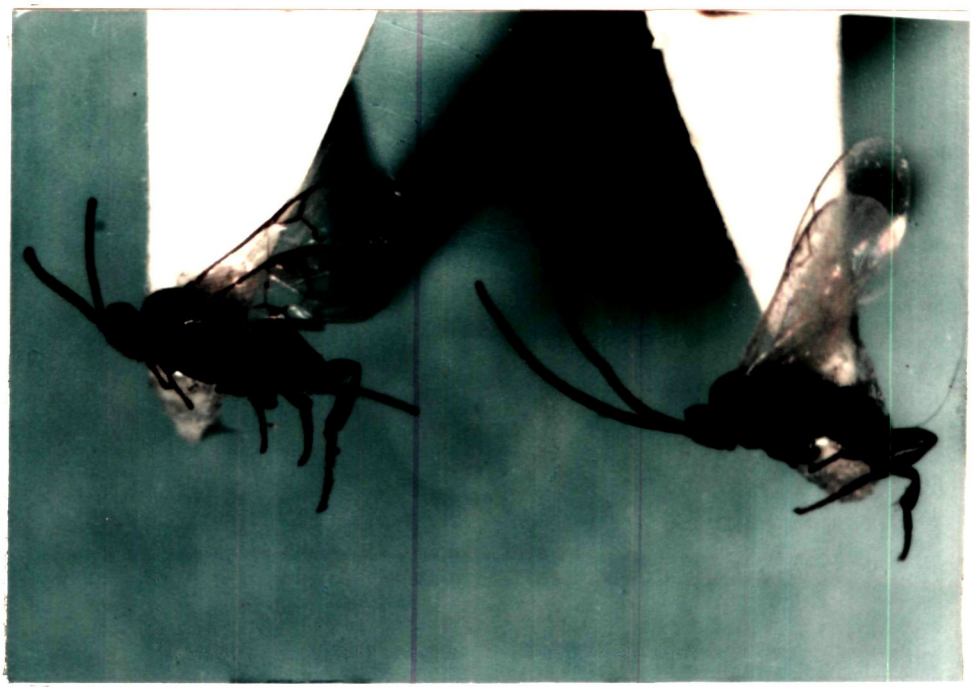


PLATE 5. Adult of *Parena nigrolineata* Chaud

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

The review of literature includes a brief note on various aspects of Opisina arenosella, Apanteles taragamae, Parena nigrolineata and spatial distribution studies.

2.1 COCONUT BLACKHEADED CATERPILLAR OPISINA ARENOSELLA WALKER

2.1.1 Description, life cycle and nature of damage

The moths are ash-grey in colour and flattened in shape. They have the habit of resting flat on the underside of the leaf or on the stem where they are quite incospicuous. The male is smaller than the female and can be further distinguished by the presence of conspicuous tuft of hair at the base of the hind wing (Rao, 1923). Male and female moths measure 20 and 28 mm respectively (Mohamed et al., 1982a). Moths are nocturnal in habit (Nirula et al., 1951a and Antony, 1962). A female moth may lay varying number of eggs from 39 to 350 in small groups (Hutson, 1922; Ghosh, 1923; Jayaratnam, 1941; Rao et al., 1948; Nirula, 1956a; Narayanan, 1954; Baburaya Nayak, 1970; Kurian and Sathiamma, 1970 and Ramachandran et al., 1979).

The egg is oval, creamy, shiny with irregular sculpturing and measures 0.6-0.8 mm long and 0.3-0.4 mm

broad. The colour changes from slight pinkish to red before hatching with a dark spot at the anterior end. The incubation period varies from 4 to 5 days (Mohamed et al., 1982a).

The larval stages varies from 5-7 instars (Rao et al., 1948; Nirula et al., 1951a; Narayanan, 1954; Nirula, 1956a, Antony, 1962; Lever, 1969; Baburaya Nayak, 1970 and Mohamed et al., 1982a). The larval period varies from 5 to 9 weeks (Hutson, 1933; Jayarathnam, 1941, Rao et al., 1948; Narayanan, 1954; Ramachandran et al., 1979 and Baburaya Nayak, 1970). The newly hatched larvae are pale white in colour and are found in groups on the undersides of leaflets. Young caterpillars are very active, usually moving restlessly over the leaflets and occasionally stopping for feeding. Their body is covered with short setae. As the larvae feed on the green matter, they assume greenish color. The larvae have different colored stripes, depending on their instars. The later instar larvae are voracious feeders and construct galleries strengthened by the excreta. The last instar larva enters into an inactive pre-pupal stage (Mohamed et al., 1982a) which lasts for 2 to 3 days (Ramachandra et al., 1979).

The pupa is brown with a circlet of hooks at the tip of the abdomen with which it gets hold to the cocoon. The moth usually emerges in about 10 to 12 days (Mohamed et al., 1982a). The total life cycle varies from 42 to 85 days (Venkatsubban, 1932; Rao et al., 1948; Narayanan, 1954; Nirula 1956a; Puttarudriah and Shastry, 1964; Baburaya Nayak, 1970 and Ramachandran et al., 1979).

Due to the feeding by larvae, the tree appears compeletely burnt and nut production reduced. Manjunath (1985) observed the caterpillars feeding on the green matter of the husk causing premature drying of nuts and thereby reducing the yield of copra.

2.1.2 Seasonal Incidence

a. In different geographical areas:

In the west coast of India, the pest occurs throughout the year and its severity increases during the hot months of March, April and May (Anstead, 1928; Nirula, 1951a; Anonymous, 1954; Narayanana, 1954; Joy and Joseph, 1972; Ramachandran et al., 1979 and Mohamed et al., 1982a). In the east coast, the pest is less active during the north east monsoon from September to December and activated during the hot months of April,

May and June. The attack of the pest was severe in Quilon town and the adjacent, Travancore during the end of May (Madhavan Pillai, 1919). In Mangalore, the attack of the pest began in December (Rao, 1923), and reached maximum development and activity during April and May (Narayanan, 1954). The pest was reported for the first time from interior Karnataka during 1964 (Puttarudraiah and Shastry, 1964).

b. Factors affecting the seasonal incidence

Both biotic and abiotic factors seem to influence the population fluctuation (Rao et al., 1948). Population decreases with the increase in relative humidity which in turn induces diseases (Anthony and Kurian, 1961; Sathiamma et al., 1972 and Ramachandran et al., 1979). Delay in the onset of rains and cessation of monsoon increases the incidence which also reduces the natural enemy population (Kurian and Sathiamma, 1970a).

Nadarajan (1977) observed the incidence of the caterpillar throughout the year in Bangalore with no particular peak season, whereas in Mangalore the pest increased during summer because of reduction in natural enemy by South west monsoon. In the coastal area the

population increased during February -May, when the maximum temperature ranged from 32 to 35°C and the maximum RH from 65 to 85% (Narendran et al., 1978).

2.1.3 Control of Opisina arenosella (= Nephantis serinopa)

2.1.3.1 Chemical Control

a. Spray and dust application

One of the earliest methods was the use of paris green for the control of O. arenosella (Kunjan Pillai, 1923). Later spraying and dusting with DDT, dieldrin., BHC, malathion, dichlorovos, trichlorfon, Aprocarb, carbaryl, monocrotophos, etc. have been found to be effective in the control of the pest (Nirula et al., 1951b; Pillai and Kurian,1960; Sathiamma et al., 1967; Kurian and Sathiamma, 1970b; Antony et al., 1971; Anjaria et al., 1975; Sathiamma and Kurian, 1972; Ramachandran et al., 1976; and Ponnamma, 1984).

Diflubenzuron, a chitin synthesis inhibitor caused morphogenetic deformities of O. arenosella pupae (Sundaramurthy and Santhana Krishnan, 1979). In the field diflubenzuran at 2.5-20 g.a.i. in 10 litres of water, eliminated Opisina population within 14 to 18 days, depending on the dose (Sundaramurthy, 1980).

b. Stem injection

Stem injection of monocrotophos at 3.5 ml active ingredient and 7.0 ml active ingredient per palm below 9 years and above 10 years, respectively gave effective control of the pest. The residues in the nut disappeared after three weeks (Nadarajan and ChannaBasavanna, 1981). Others who have reported stem injection for the control of leaf eating caterpillar include Rao et al. (1981), Kanagaratnam and Pinto (1985), Sundaramurthy and Jayaraj (1985).

c. Root feeding

The systemic insecticide monocrotophos fed through single matured root for the control of coconut black headed caterpillar at 18 and 9 ml gave complete control of the pest for 90 days in palms above 10 years and below 10 years respectively (Pushpalatha, 1986). When monocrotophos was fed at the rate of 5 g active ingredient per palm, the residues in coconut water and copra were reduced to below detectable levels, 60 days after treatment (Rao and Murthy, 1985). Ganeswara Rao et al., (1980) and Ponnamma and Abraham (1981) have also tried root feeding with monocrotophos.

2.1.3.2 Biological control

The coconut leaf eating caterpillar supports over

24 species of parasitoids and six species of predators in India and in Sri Lanka (Dharmaraju, 1962; Mohammed et al., 1982a and Pillai and Ramachandran Nair, 1983). Of these, the larval parasitoids Apanteles taragamae Wilkinson, Bracon brevicornis Wesmael, B. hebetor Say, Perisierola nephantidis Muesebeck, Spoggosia bezziana (Baranoff) and Elasmus nephantidis Rohwer and the pupal parasitoids Brachymeria nosatoi Habu, B. nephantidis Gahan, Trichospilus pupivora Ferriere, Xanthopimpla punctata Fabricius and X. nana nana Schulz are the well known species which exert considerable check on pest population in nature (Pillai and Ramachandran Nair, 1986).

Rao et al., (1948) have given a detailed account of the biological control of this pest. Parasierola nephantidis (Muesebeck) was first observed on O. arenosella larvae in Coimbatore by Rao and Cherian (1928). Natural parasitism of 9.6 per cent during 1969-70 was reported by Baburaya Nayak (1970). A higher parasitisation was observed in February 1975 (42.9%) and March 1975 (48%) and lower incidence during April (1.9%) and June 1975 (1.6%) (Nadarajan and ChannaBasavanna, 1980). Medappa (1983) reported that release of 10 parasitoids per palm coupled with partial mechanical removal and destroying of infested leaflets gave a good

control of O. arenosella. George et al., (1977) conclude that the increase in parasitism is directly proportional to the abundance of the host material and have found Perisierola nephantidis to be the most efficient larval parasites.

Gulagannavar (1984) reported three species of carabid predators, an arboreal ant and 14 species of spiders feeding on this pest. However, most commonly occurring predators reported are Parena nigrolineata, Oecophylla smaragdina among insects and three species of Cheirocanthium, two species of Olios and two species of Phidippus among spiders.

Twenty one species of chalcid parasitoids of Opisina arenosella Walker have been dealt briefly by Narendran (1985).

2.2 APANTELES TARAGAMAE VIERICK

2.2.1 Distribution and extent of parasitism

Originally described by Vierick (1912), A. taragamae (Hymenoptera:Braconidae) occurs all over the east coast districts from Vizagapatnam down to South Arcot and Salem (Rao et al., 1948). It functioned as an efficient check on the pest in the east coast and in the states of Tamil Nadu and Orissa. Although rarely

present in the west coast, it was found to establish normally when introduced from the east coast. No record was made in Sri Lanka (Nirula, 1956b).

The parasitoid was introduced along with the bethylid Brasiorola nephantidis, into Mangalore area in 1924 and 1925 with fairly successful results and subsequently into the Ponnani and other South Malabar areas in 1926, 1927 and 1928, where its efficiency was found to be impaired by the activity of hyperparasites (Rao et al., 1948).

According to Mohamed et al., (1982a), in Kerala, the highest larval parasitism was due to A. taragamae which played a significant role in checking the pest from the very beginning. Of the total 8242 larvae collected from the field, 5.43% larvae were parasitised by A. taragamae, Brasiorola nephantidis, Bracon brevicornis and Elasmus nephantidis and the highest percentage parasitism of 3.18 was by A. taragamae. Out of the total 11,724 larvae and pupae of the host collected from the field, 8.39% were subjected to attack by the parasitoids. The highest percentage of parasitism (2.24) was by A. taragamae.

2.2.2 Description and Biology

The adult is a small black coloured wasp measuring 3-4 mm long. The female wasp bears a prominent dark brown colored ovipositor (Rao et al., 1948; Baburaya Nayak, 1970). They are solitary parasitoids attacking early instar larvae (Rao et al., 1948; Nirula, 1956b; Baburaya Nayak, 1970 and Mohamed et al., 1982a).

Due to the difficulty in rearing the parasitoid in the laboratory, limited information on its life history is available. Rao et al., (1948) observed that the wasp thrust its ovipositor through the larval gallery to lay a single egg on young caterpillars. The larva, develops as an internal parasitoid, consuming the body fluid and then constructs an elongate, white cocoon within the galleries. The adult parasitoid emerged out of the cocoon by pushing open a neatly cut lid at one end.

The female wasp usually parasitized second instar larvae and sometimes first instar. The parasitised host larva was observed to develop normally for sometime, but later became thin and pale (Nirula, 1956b).

The life cycle took about 10-14 days (Rao et al., 1948; Nirula, 1956b). Development from egg to adult took 15 days during hot months and 24 days during cold

months. The $\sigma^{\nearrow}$: O_{+} ratio varied from 1:1 to 2:3. In the laboratory the females laid most number of eggs on the second day after emergence and preferred host larvae in galleries. The frass produced by the host larva was a strong attractant for the females and stimulant for egg laying (Ghosh and Abdurahiman, 1988).

2.2.3 Hyperparasitoids

Though the parasitoid is a very efficient natural enemy, its activity is restricted by the presence of hyperparasitoids. The hyperparasitoids of A. taragamae are Calliceras manilae Ashm. (Calliceratidae), Eurytoma albotibialis Ashm. (Eurytomidae), Perilampus microgastris Ferr. (Perilampidae) and Brachymeria nephantidis Gahan. (Chalcidae) (Rao et al., 1948; Nirula, 1956b). Ghosh and Abdurahiman (1985) found A. taragamae parasitized by the pupal parasitoids of O. arenosella, viz. Pediobus imbreus and Eurytoma braconidis Ashm. (Eurytomidae). Similarly, two other primary parasitoids of Opisina arenosella, namely Meteoridea hutsoni Nixon (Braconidae) and Elasmus nephantidis Rohw. (Elasmidae) were also found to be hyperparasitoids of A. taragamae (Ghosh and Abdurahiman, 1986).

2.3 PARENA NIGROLINEATA (CHAUDOIR)

P. nigrolineata (= Phlaeodromius nigrolineatus) (coleoptera: Carabidae) a predator of Bombyx mori L. (Nishikawa, 1919), Hyblaea puera Cramer, Sylepta derogata Fabr., Nephopteryx rhodobasalis Hamps., Pyrausta machaeralis Walk. and Atteva fabriciella Swed. (Mohamed et al., 1982b), was first recorded feeding on O. arenosella in Mangalore, Karnataka (Rao, 1924).

It's presence has been recorded from several places in Kerala (Venkatasubban, 1932; Mohamed et al., 1982), South East Asia including Sothern China and Japan (Gardener, 1933). It is distributed in east coast (Rao et al., 1948) and in Karnataka (Medappa, 1983; Gulagannavar, 1984). In Sri Lanka, Dharmaraju (1963) for the first time observed and recorded the larvae and adults of P. nigrolineata preying on O. arenosella.

The beetle mostly feeds on the larval stages of O. arenosella (Rao, 1926; Dharmaraju, 1963; Mohamed et al., 1982b; Medappa, 1983 and Gulagannavar, 1984), feeding on the pupae, is not uncommon (Rao, 1924 and Venkatasubban, 1932).

The eggs of the beetle are oval and white in colour. The campodeiform larva passes through three instars and the pupa is exarate. The beetle is shiny and dark brown (Mohamed et al., 1982b; Gulagannavar, 1984 and Pillai and Kesava Bhat, 1987).

The beetles and grubs are active throughout the year, with high populations from June to January. Oviposition activity is throughout the year, with peak oviposition during June to December (Gulagannavar, 1984). Increase in relative humidity increases the fecundity and per cent hatch (Gulagannavar, 1984 and Pillai and Kesava Bhat, 1987).

A scelionid, egg parasitoid Xenomerus Sp. brings down the population of P. nigrolineata in the field (Pillai and Kesava Bhat, 1987).

2.4 SPATIAL DISTRIBUTION

The spatial pattern of plants and animals is an important characteristic of ecological communities. It is one of the first observations made in viewing any community and is one of the most fundamental properties of any group of living organisms (Cornell, 1963). The pattern of spatial distribution not only affects the precision of the estimation of population parameters in

sampling, but also the method of analysis of the data. The distribution at a given time is determined by a complex of biological process that are occurring in the population of that time and it may define the subsequent changes (Waters, 1959). The understanding of distribution is important for analysing predator-prey and host-parasite relationship (Crofton, 1971; Murdie and Hassell, 1973; Anderson, 1974); for pest sampling, programs in agriculture and medicine; and for any animal survey or forecasting methodology (Taylor, 1984).

The spatial distribution, in general follows random, clumped and uniform patterns. Because of their variance to mean properties some of the statistical frequency distributions, that have been suggested as models of the ecological patterns are

1. The poisson distribution ($\sigma^2 = \mu$) for random patterns.

2. The negative binomial ($\sigma^2 \geq \mu$) for clumped patterns.

3. The positive binomial ($\sigma^2 \leq \mu$) for uniform patterns.

Though these three statistical models have been commonly used in spatial pattern studies, Pielou (1977) suggests that other statistical distributions might be equally appropriate.

2.4.1 Poisson Distribution

For a randomly dispersed population of organisms, the poisson model (variance equals mean) gives probabilities for the number of individuals per sample unit, provided the following conditions hold (John and James, 1990):

1. Each natural sample unit has an equal probability of hosting an individual,
2. the occurrency of an individual in a sample unit does not influence its occupancy by another,
3. each sample unit is equally available, and
4. the number of individuals per sample unit is low relative to the maximum possible that could occur in the sample unit.

Cole (1946) observed the distribution of spiders corresponding to a poisson distribution. Animals at low population were reported to have a distribution similar to that of poisson. But it do not necessarily mean that animals are distributed randomly under these

conditions. Even if insects have some aggregation tendency, due to statistical deficiency, frequency distribution of a small number of insects usually cannot depart noticeably from poisson expectation (Waters and Henson, 1959).

2.4.2 Negative Binomial Distribution

The negative binomial model is the most commonly used probability distribution for clumped or contagious or aggregated populations (Bliss and Fisher, 1953; Sokal and Rohlf; 1981) and was the most widely adaptable and generally useful (Bliss, 1941). The negative binomial does not fit well at low or very high densities (Taylor, 1984). When two of the conditions associated with the use of poisson model are not satisfied, i.e. (i) each natural sample unit has an equal probability of hosting an individual and (ii) the occurrence of an individual in a sample unit does not influence its occupancy by another, it usually leads to a high variance to mean ratio of the number of individuals per sample unit that a clumped pattern may exist (John and James, 1990). Negative binomial has endless speculative functional mechanisms. It is defined by two parameters, the arithmetic mean (m) and a positive exponent (k), but k is not a predictable parameter except over small

ranges. It is not consistent within species, nor is it consistently different between species over long ranges of population density. The negative binomial is a useful tool for graduating data, but it cannot be used in population models unless the variance/mean parameters are first specified in order to derive the relationship 1/k x m. It is difficult to trace the source of the claim that k is an index of aggregation with any kind of biological definition; its statistical definition is irrelevant without this evidence (Taylor, 1984).

The distribution of third instar larvae of the European Chafer (Amphimallon majalis) per square foot in a 25' x 25' area of permanent pasture was fitted by the negative binomial distribution, but it was approximately random in each sub area of 5'x5' (Burrage and Gyrisco, 1954). Negative binomial distribution was followed by spruce bud worm, Choristoneura fumiferana (Morris, 1955), immature stages of eye spotted budmoth (Spilonota ocellana) and pistol casebearer, Caleophara servatella (LeRoux and Reimer, 1959), eggs of cabbage butterfly (Pieris rapae) (Harcourt, 1961b; Kobayashi, 1966 and 1968) and most of the stages of balsum wooly aphid (Amman, 1969).

The numerical changes in space and time in a population of citrus leaf miner (Phyllocnistis citrella) was studied by Ikemato (1972). They observed the eggs and larvae to follow contagious distribution. Contagious populations have been expressed by the negative binomial distribution in the case of Thrips tabaci (Suman et al., 1980a), Crocidolomia binotalis (Suman et al., 1980b), Amrasca biguttula biguttula (Srinivasan et al., 1981) and Citrus green scale on mandarin (Tandon, 1985). The negative binomial distribution fitted very well to the spatial distribution of aphids in the field and provided an explanation of the patchy spread of tristeza disease (Seif and Islam, 1988). The data an Thrips palmi fitted a negative binomial model with a probability range of 0.01 to 0.70 (Verghese et al., 1988b).

2.4.3 Indices of Aggregation

The relative degree of aggregation or departure from randomness of the observed distribution can be measured by the indices of aggregation. The index of aggregation is a more feasible approach to analyse than the frequency distribution because it makes less demands on the data and various indices of dispersion have been proposed.

When a population is sampled, three basic bits of information are available; (i) the estimate ($\bar{X}$) of the true mean, m (ii) the estimate (s^2) of the true variance (σ^2) and (iii) the size (unit). The indices used for the description of animal populations are derived from various arrangements of this information (Southwood, 1978).

a. Variance to mean ratio

The simplest index, and the most fundamental is the variance to mean ratio. The value of variance to mean ratio is unity for poisson distribution and less than unity for regular distribution and more than unity for aggregated distribution.

b. Taylor's Power Law

A considerable number of species of various kinds of organisms had an element in their spatial distribution that, while not constant at all densities related variance consistently to density, $S^2 = a\bar{x}^b$ (Taylor, 1958). It is useful in sampling crops, in aerial monitoring and forecasting and to interpret pest behaviour during seasonal redistribution between different hosts (Taylor, 1984). But Iwao and Kuno (1971) suggest this to be an empirical relationship which is not suitable for analytical purpose.

c. k of Negative binomial

The parameter k is a general, reciprocal index of 'dispersion' that also arises as the parameter of the negative binomial (Taylor, 1984). It is most common in insects. It is given as $k = \bar{X}^2/s^2-\bar{X}$. If k is around 2, then the distribution is aggregation, if greater than 2, approaches random and less than 2 approaching zero, it is highly clumped. k would be a good measure of aggregation because of the wide applicability and flexibility of the negative binomial (Waters, 1959). Since k becomes infinite as the distribution becomes random, it is preferable to use 1/k which takes the value zero for a random distribution and increases as overdispersion increases (Cassie, 1962). Size of sampling influences the value of k, hence comparison can only be made using the same sample size (Tandon, 1985). But within the restriction, it does provide a useful measure of the degree of aggregation of the particular population varying with the habitat and 'developmental (Dybas and Davis, 1962).

d. Morisita's Index Is

An index intended to be free from frequency distributions, initially to investigate the effects of quadrat size on the average number of individual was

developed by Morisita, (1954 and 1959). It was derived from a consideration of spacing analysis (Morisita, 1957). The basic premise is that all spatial distribution becomes random or regular when quadrat size is made sufficiently small. The index is useful for measuring the relative degree of departure from randomness. By using the change of index value with the increase of quadrat size, the more detailed nature of the observed distribution, such as approximate size of clumps and the pattern of intra clump distribution can be detected. But, if the distribution is colonial, the value of index decreased with increasing colony density even when no changes occur in the distribution pattern and mean size of colonies. Hence Morisita's (1959) index is not satisfactory in describing the aggregation pattern characteristic of the species (Iwao and Kuno, 1971).

e. Lloyd's index of mean crowding(m^*)

"Mean crowding" is defined as the mean number of other individuals per individual per quadrat (Lloyd, 1967). It is a more sophisticated measure of "crowding" than mean density for the analysis of density dependence in insect population. It indicates the possible effect of mutual interference or competition among individuals.

Lloyd (1967) introduced another measure called "patchiness", which is the ratio of mean crowding to mean density. If the value is less than, equal to or greater than one, it indicates uniform, random and aggregated distribution, respectively. The mean crowding and patchiness only have meaning when the population is loosely aggregated and the quadrat size is not too large as compared with the "ambit" of an individual (Lloyd, 1967). However, Iwao (1968 and 1970) claimed that these parameters can be used for any kind of organism or quadrat, without special reference to "biological interactions".

f. Iwao's Patchiness Regression ($X^* = \alpha + \beta \bar{x}$)

The mean crowding can be regressed on mean density. The resulting relationship has been treated as linear by Iwao (1968 and 1970a) to yield two regression coefficients, α the intercept and β the slope, to be used as population parameters. From the patchiness regression ($X^* = \alpha + \beta \bar{x}$), the constant α termed as 'Index of basic contagion' by Iwao (1970b) indicates the tendency to crowding or repulsion. The coefficient β which is called as 'Density contagious coefficient' is related to the pattern in which organism utilises its habitat. β equal to, greater than and less than unity

indicates random, contagious and regular distribution respectively.

Various indices of aggregation were used to stud the spatial distribution of Amrasca biguttula biguttula on Okra (Srinivasan et al., 1981), Cocus viridis on mandarin (Tandon, 1985), Erosomyia indica on mango (Verghese et al., 1988a) and Thrips palmi on mango (Verghese et al., 1988b). Taylor's power law provided a better description of variance mean relationships for Broad mite and Citrus rust mite on lime trees than did Iwao's patchiness regression(Jorge and Baranowski, 1990).

2.5 SAMPLE SIZE

In a habitat, it is not possible to count all the insects, hence the population can be estimated by sampling. The total number of samples depends on the degree of precision required. This may be expressed either in terms of achieving a standard error of a predetermined size, or in probability terms, getting confidence limits of a predetermined half-width, a percentage of the mean (Karandinos, 1976).

Southwood (1978), suggested a method to obtain the optimal sample size for which the distribution pattern

of the insect must be known, and the variance of intra-plant samples (S_s^2) must be compared with inter-plant samples variance (S_p^2). This should be set against the cost of sampling within the plant (C_s) or of moving to another plant and sampling within it (C_p). Another formula suggested for homogenous habitats by Southwood (1978) is: $n = \left(\frac{S}{EX}\right)^2$, where the standard deviation (s) of the observations is compared with the standard error (EX) acceptable for the contrast we need to make. In any given situation the value of standard error will change with the square root of the number of samples. Thus a large increase in 'n' is a must to bring a small improvement in standard deviation.

For sampling at two levels, e.g. number of clusters per tree and number of trees, Harcourt (1961a) proposed the formula

$$n_s = \frac{S_s^2/n_s + S_p^2}{(\bar{X} \times E)^2}$$

where n_s = the number of samples within the habitat unit, S_s^2 = intraplant variance, S_p^2 = interplant variance, $\bar{X}$ =mean per sample, and E = the pre-determined standard error as a decimal of the mean (normaly 0.05).

Rojas (1964) showed that if the dispersion of the population is well described by the negative binomial, the desired number of samples can be calculated by

$$N = \frac{1/X + 1/K}{E^2}$$

Southwood (1978) suggests another forumla $N = \frac{t^2 pq}{D^2}$

where p = the probability of occurrence, q = 1-p, t = students t and D = the pre-determined half-width of the confidence limits. This concerns the measurement of the frequency of occurrence of a particular organism or event. Before an estimate can be made of the total number of samples required, an approximate value of the probability of occurrence must be obtained.

For estimating the population densities of Toxoptera citricida in citrus, Seif and Islam (1988) used the formula suggested by Southwood (1978).

$$n = \sqrt{\frac{S_s^2}{S_p^2} \times \frac{C_p}{C_s}}$$

Verghese et al., (1988b) used the formula of Sukhatme and Sukhatme (1977) for calculating the optimum sample number of panicles for estimating the density of

Thrips palmi, with margins of error at 5, 10, and 20 per cent (d) with reference to mean values at 5 and 10 per cent confidence limits (t value). This they compared with the sample size (q) worked out on the distribution pattern, as per Iwao's (1977) formula.

$$q = \frac{1}{D^2}\left(\frac{\alpha + 1}{m} + \beta - 1\right)$$

where D = standard error of mean, m = mean, α = index of basic contagion and β = density contagion coefficient.

Sample size requirement for the Broad mite and the Citrus rust mite, for fixed levels of precision, were determined by using estimated variance - mean relationships obtained from Taylor's power law regressions (Jorge and Baranowski, 1990).

Iwao and Kuno (1968) have developed a general formula based on the regression of mean crowding (m^*) on mean (m). This method has an advantage over conventional methods if the relative degree of aggregation (m^*/m) remains constant over a range of densities. The equation for the required sample size in case of simple random sampling is given by :

$$q = 1/d^2 \left[(\alpha + 1)_m + (\beta - 1)^2_m \right]$$

Cochran (1977) suggested a general forumala

$$n = \frac{(\frac{t_s}{d})^2}{1 + \frac{1}{N}(\frac{t_s}{d})^2}$$

where n = number of samples, d is the chosen margin error between sample mean and population mean, t is ordinate value of the normal curve that cuts off an area at the tails, s is the standard deviation and N is the original sample size considered for estimation. Tandon (1985) usd the above formula for calculating the optimum number of leaf samples required for estimating the mean density of Coccus viridis in mandarin.

2.6 TRANSFORMATION

Before subjecting the data on insect population to analysis of variance, the distribution should be normalized and the variance should be made independent of mean. Hence, the original data have to be transformed, i.e. the actual numbers are replaced by a function whose distribution is such that it normalizes the data or stabilizes the variance. It should be undertaken only when the conditions for statistical tests are grossly violated (Le Roux and Reimer, 1959; Finney, 1973).

In practice where sampling and other errors are fairly large, it will usually be found adequate to transform the data from a regular population by using squares, that from a slightly contagious one by using square roots and from distinctly aggregated or contagious populations by using logarithms (Southwood, 1978).

To overcome difficulties with zero counts in log transformations, the transformation "log (x+1)' is suggested by Southwood (1978) and log (x+k/2) by Anscombe (1948) where k is the dispersion parameter of the negative binomial. Andersen (1965) has suggested the pooling of independent samples or increasing the size of the sample unit for transformation, because if the mean and k are very small then the variance will not be stabilized by $k^{1/2}$ or any of the common transformations.

Arcsin transformation is only of value when the probability of finding the individual bearing the attribute is uniform within each area (for which a per cent infestation has been calculated), but varies considerably between the different classes (whose per cent infestation values one wish to analyse). Even in such cases it is necessary only when a number of the

per cent points lie outside the 20-80 range. When the various percentages are based on grossly unequal number of individuals, they will need to be weighted before the analysis of variance can be applied (Reimer, 1959).

Tandon and Veeresh (1987) tested six transformations, viz. log (x+1), log (x+k), Sinh-1$\sqrt{\frac{\beta-1}{\alpha+1}}$ x $x^{1-b/2}$, log [log (x+2)] and log [log (x+k)] for their efficiency in stabilizing variance of Coccus viridis (green) population counts which followed negative binomial distribution and found only log [log (x+2)] transformation to be effective in stabilizing variance. For the data on percentage infestation of Erosomyia indica on mango, angular transformation was found to be satisfactory (Verghese et al., 1988a). Of the various transformations applied for the data on Thrips palmi on mango, Verghese et al., (1988b) found the transformations log (x+1), log (x+k/2), log [log (x+2)] and $\text{Sin}^{h-1}\sqrt{\frac{\beta-1}{\alpha+1}}$ x to be suitable for normalizing the data.

2.7 INTERSPECIFIC ASSOCIATIONS

Interspecific association is defined as the tendency of species to occur together more (or less) often than is to be expected on the basis of chance

alone (Hurlbert, 1969). He suggests the ability to express quantitatively the extent to which two species occur together as a useful tool for ecologists. The measurement of interspecific association is of value for detection of interactions between species and similarity of habitat requirements (Cole, 1949) and provides an objective method for recognizing natural groupings of species in a community (Smith, 1980).

Interspecific association may result from species interaction, food chain co-action, or similarity in adaptation and response to the environment (Smith, 1980). Two types of association occur namely a positive association which occurs when two species exhibit overlapping "habitat" requirements or interact in such a way as to favour mutual presence (Cole, 1949) and a negative association which occurs when two species possess different habitat requirements or interact in a way that is deterimental to one or both species, i.e. interspecific competition (Smith, 1980).

Joseph and Winfield (1983), studied the interspecific association between the red imported fire ant, Solenopsis invicta Buren, and several insect inhabitants of east Texas Cotton fields. Positive

association values were observed, indicating that ants occurred in combination with aphids and several hemipteran predators, more frequently than expected on the basis of chance alone.

Verghese and Tandon (1987), studied the interspecific associations among Aphis gossypii, Menochilus sexmaculatus and Camponotus compressus. They observed a positive association of M. sexmaculatus and C. compressus with A. gossypii and a negative association between M. sexmaculatus and C. compressus.

MATERIALS AND METHODS

III MATERIALS AND METHODS

Studies on population ecology of Opisina arenosella were undertaken at Nagenahalli, Hebbal, Bangalore. The study site is located at an altitude of 899 m above mean sea level with a latitude of 13°N and a longitude of 77° 37'E.

The coconut grove at Nagenahalli has around 140 uniformly spaced 20 year old trees. No control measures were taken in the plot in the past and during the study period. The plams are spaced in seven rows with 20 trees in each row.

3.1 SEASONAL POPULATION FLUCTUATIONS

The observations on seasonal population fluctuations were made once a month from January 89 to December 89. Ten trees were randomly selected from the Nagenahalli plot. From each tree 120 leaflets were plucked at random, from all over the canopy. The leaves were examined in the laboratory and the number of O. arenosella larvae present along with its natural enemies were recorded.

Data on weather factors were obtained from the meteorological observatory at the Main Research Station, Hebbal, Bangalore, located at about 2km from the study

site. The monthly averages of maximum and minimum temperature, percentage relative humidity at 7.20 hrs, rainfall and sunshine hours were correlated with monthly O. arenosella and its natural enemies populations.

3.2 INTRA-TREE DISPERSION

Studies on Intra-tree spatial distribution were carried out in two seasons. Sampling was done when the population was at its peak, i.e. during March to May 1989 and in the lean period, i.e. during September to November 1989 at Nagenahalli. Thirty trees were randomly selected from the grove. From each tree, 120 infested leaflets were randomly plucked from all over the conopy. In the laboratory, each leaflet was examined for the number of larvae. From the data obtained, various statistical parameters of spatial distribution viz. Variance- mean ratio, mean crowding, Lloyd's (1967) index of patchiness and k value were calculated. The observed spatial distribution was further analysed by using Iwao's (1968) patchiness regression. Chi square test was conducted and probability of fit was calculated.

During the lean population period of O. arenosella, only 17 trees data could be statistically analysed since the remaining trees had very negligible population.

3.3 INTER-TREE DISPERSION

For the study on inter-tree distribution, twenty five trees were randomly selected in the peak season and seventeen trees in the lean season. From each tree, 120 infested leaflets were plucked and brought to the laboratory and the number of larvae in each leaflet was recorded.

As in the case of intra-tree spatial distribution, the data were subjected to statistical analysis.

3.4 INFLUENCE OF DIRECTION ON POPULATION DISTRIBUTION OF *O. arenosella*

The study was made on 20 trees each in peak (March to May 1989) and lean (September to November 1989) infestation periods. To ascertain the influence of direction on the distribution of the pest, the canopy of each tree was divided into four directional quadrants, viz. North, South, East and West. Further the tree was divided into upper and lower canopy regions. From each of the eight quadrants, 15 leaves were sampled. The number of larvae in each leaflet were recorded in the laboratory. The data were subjected to analysis of variance.

3.5 DISTRIBUTION OF O. arenosella IN RELATION TO TREE HEIGHT

For this study, 20 trees were selected in the two infestation periods when the insect attack reached the extreme levels. The tree canopy was divided into upper and lower regions. From each region, 60 leaflets were collected at random and the number of larvae in each leaflet was recorded. The data were subjected to analysis of variance.

3.6 DISTRIBUTION OF O. arenosella IN RELATION TO FROND POSITION ON THE TRUNK

This study was made at Nagenahalli in February, 1990. Five trees were randomly selected from the plot and the 1^{st}, 5^{th}, 10^{th} and 15^{th} frond from the base of each tree were selected. From each frond, 30 leaflets were randomly picked and brought to the laboratory. The number of larvae ineach leaflet was counted and the data were subjected to analysis of variance.

3.7 DISTRIBUTION OF O. arenosella WITHIN A FROND

Five trees were randomly selected and four fronds from each tree were cut. Each frond was visually divided into three regions, i.e. base (x_1), middle (x_2) and apex (x_3). Ten leaflets from each region were picked and the

number of larvae in each leaflet was recorded. The data were sujbected to analysis of variance. Mean, variance and variance mean ratio were calculated. Correlation coefficients (r) of larval population in different regions (base, middle and apex) with total population (x_4) in the frond were computed.

3.8 DISTRIBUTION OF O arenosella WIHIN A LEAFLET

From the coconut grove a total of 100 leaflets were picked from a few randomly selected trees. Each leaflet was divided into three regions, viz. base (x_1), middle (x_2) and apex (x_3) and the number of larvae in each region was recorded. The data were subjected to analysis of variance. The mean, variance and the variance mean ratio were calculated. In addition, the correlation coefficients (r) of the larval population in different regions (x_1, x_2, x_3) with total population (x_4) in the leaflet were computed.

3.9 INTERSPECIFIC ASSOCIATIONS AMONGST Opisina arenosella, Apanteles taragamae and Parena nigrolineata

To study the association between O. arenosella, A. taragamae and P. nigrolineata, ten trees were randomly selected from the grove at Nagenahalli. The

study was made in June 1990. From each tree 120 leaflets were picked. The number of O. arenosella, A. taragamae and P. nigrolineata present were recorded. The means and variances of these data for the three species were calculated. To determine the type of association between O. arenosella and A. taragamae, O. arenosella and P. nigrolineata and A. taragamae and P. nigrolineata, a 2x2 contigency table as suggested by Southwood (1978) was used. The data were subjected to Iwao's (1979) analytical method, to quantify the association.

3.10 SELECTION OF SAMPLE SIZE

Sample size requirements for fixed levels of precision were determined by using estimated variance-mean relationships obtained from Taylor's power law regression.

3.11 APPROPRIATE TRANSFORMATION FOR O. arenosella POPULATION

For 20 sets of data on O. arenosella population, various transformations, viz. log(x+1), log(x+k), (Kleczkowaskii, 1949), log [log(x+2)] (Tandon, 1985, $\text{Sinh}^{-1}\sqrt{\frac{\beta - 1}{\alpha + 1}}\, x$ (Iwao and Kuno, 1971), $X^{1-b/2}$ (Taylor, 1961), log (x+k/2) (Anscombe, 1948) and $\sqrt{x+1}$ (Bliss and Fisher (1953) were applied. The means and variances

for the transformed data and for the original counts were computed. The correlation coefficient (r) between mean and variance was used to test the independence of variance and mean (Morris, 1959).

3.12 STATISTICAL FORMULAE

1. $$\text{Variance} = s^2 = \frac{\sum (x - \bar{x})^2}{n - 1}$$

where x = number of larvae/sample

$\bar{x}$ = mean density

n = sample size

2. $$\text{Variance mean ratio} = s^2/\bar{x}$$

where s^2 = variance

$\bar{x}$ = mean density

3. k value : It was calculated by using Anscombe's (1949) formula.

$$k = \frac{\bar{x}^2}{s^2 - \bar{x}}$$

where $\bar{x}$ = mean density

s^2 = variance

4. Index of mean crowding (X^*): It was calculated by using Lloyd's (1967) formula:

$$x^* = \bar{x} + \left(\frac{s^2}{\bar{x}} - 1\right)$$

where $\bar{x}$ = mean density

s^2 = variance

5. Lloyd's index of patchiness:

$$= \frac{x^*}{\bar{x}}$$

where x^* = index of mean crowding

$\bar{x}$ = mean density

6. Mean size of clump: (Arbous and Kerrich's, 1951)

$$\lambda = \frac{\bar{x}}{2k} V$$

where $\bar{x}$ = mean density

V = function with chi square distribution with 2k degree of freedom.

7. Iwao's (1968) patchiness regression

$$x^* = -\alpha + \beta \bar{x}$$

where x^* = index of mean crowding

$\bar{x}$ = mean density

α = index of basic contagion

β = density of contagiousness coefficent

8. Taylor's power law regression

$$\sigma^2 = a\ u^b$$

σ^2 = variance

μ = mean

Coefficient a and exponent b are estimated by linear regression of log s^2 on log $\bar{x}$.

s^2 = sample variance

$\bar{x}$ = sample mean

Precision was defined $S/D = S\bar{X}/\bar{x}$

$S\bar{X}$ = Standard error of mean

Values of D = 0.10, 0.15 and 0.25 (Southwood, 1978).

9. 2 x 2 Contingency table analysis

A 2 x 2 contingency table as suggested by Southwood (1978)

Species Y	Species X		
	Present	Absent	
Present	a	b	a+b
Absent	c	d	c+d
	a+c	b+d	n = a+b+c+d

The association is positive (affinity) if ad is greater than bc, and negative (repulsion) if ad is less than bc.

10. Iwao's (1979) spatial association analysis.

(i) Interspecies mean crowding values (m^*_{xy}, and m^*_{yx}, i.e. mean crowding on species X by species Y, and vice-versa).

$$m^*_{xy} = \frac{\sum_{j=1}^{Q} X_{xj} X_{yj}}{\sum_{j=1}^{Q} X_{xj}} \quad \text{and}$$

$$m^*_{yx} = \frac{\sum_{j=1}^{Q} X_{xj} X_{yj}}{\sum_{j=1}^{Q} X_{yj}}$$

where X_{xj} and X_{yj} = Number of individuals of species X and species Y in the j^{th} leaf.

(ii) Degree of overlapping index

$$r = \sqrt{\frac{m^*_{xy} \; m^*_{yx}}{(m^*_x + 1)(m^*_y + 1)}}$$

$$r_{(ind)} = \sqrt{\frac{m_x \, m_y}{(m^*_x + 1)(m^*_y + 1)}}$$

where m_x = mean density of species X

m_y = mean density of species Y

m^*_x = mean crowding values of species X

m^*_y = mean crowding values of species Y

ind = independent

(iii) Degree of spatial correlations (w)

$$W + = \frac{r - r_{(ind)}}{1 - r_{(ind)}}, \text{ when } r \geq r \text{ (ind)}$$

or

$$w - = \frac{r - r_{(ind)}}{r_{(ind)}}, \text{ when } r \leq r \text{ (ind)}$$

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

4.1 SEASONAL POPULATION FLUCTUATIONS OF O. arenosella IN RELATION TO ABIOTIC AND BIOTIC ENVIRONMENTAL FACTORS

Table 1 presents the data on the population fluctuation of O. arenosella in relation to abiotic and biotic environmental factors (Fig.1 and Fig.2), viz. mean rainfall mm (x_1), mean maximum temperature ^{o}C (x_2), mean minimum temperature ^{o}C (x_3), mean percentage relative humidity at 0720 hrs (x_4), mean sunshine hours per day (x_5), total G. nephantidis population (x_6), total A. taragamae population (x_7) and total P. nigrolineata population (x_8) for the year 1989.

The population of O. arenosella was highest (5121/1200 leaflets) during May when the average fall was 1.53 mm and least (26) during October. When the average rain fall was highest (8.18 mm) There was no rainfall from January 1989 to March 1989 and again in December 1989. The population was quite substantial when there were no rains.

The maximum mean temperature was lowest (26.5^{o}C) during the month of December, when the pest population

Table 1: Population fluctuation of O. arenosella in relation to various biotic and abiotic environmental factors (1989)

Month	Mean rainfall (mm)	Mean temperture (°C) Maximum	Minimum	Mean relative humidity(%) at 0720	Mean sunshine (hours/day)	Total G. nephantidis Population	Total A. taragamae Population	Total P. nigrolineata Population	Total O. arenosella Population
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
January	0.00	26.9	13.90	93.00	8.2	2.00	29.00	0.00	1174
February	0.00	30.5	12.30	84.00	10.7	4.00	19.00	2.00	1318
March	0.00	31.8	17.30	81.00	10.0	0.00	45.00	0.00	4118
April	0.02	34.1	21.20	83.00	6.5	2.00	59.00	4.00	1688
May	1.53	33.9	21.40	86.00	9.0	0.00	41.00	2.00	5121
June	1.72	30.3	20.00	93.00	6.6	1.00	50.00	41.00	1697
July	5.88	28.0	19.90	96.00	5.5	12.00	30.00	1.00	117
August	1.52	28.3	19.40	96.00	5.9	2.00	16.00	1.00	624
September	7.19	28.7	19.50	95.00	6.2	0.00	19.00	4.00	222
October	8.18	28.9	18.60	95.00	4.0	2.00	2.00	0.00	26
November	0.30	27.1	16.00	94.00	5.2	0.00	0.00	0.00	92
December	0.00	26.5	16.10	95.10	5.89	0.00	5.00	0.00	271

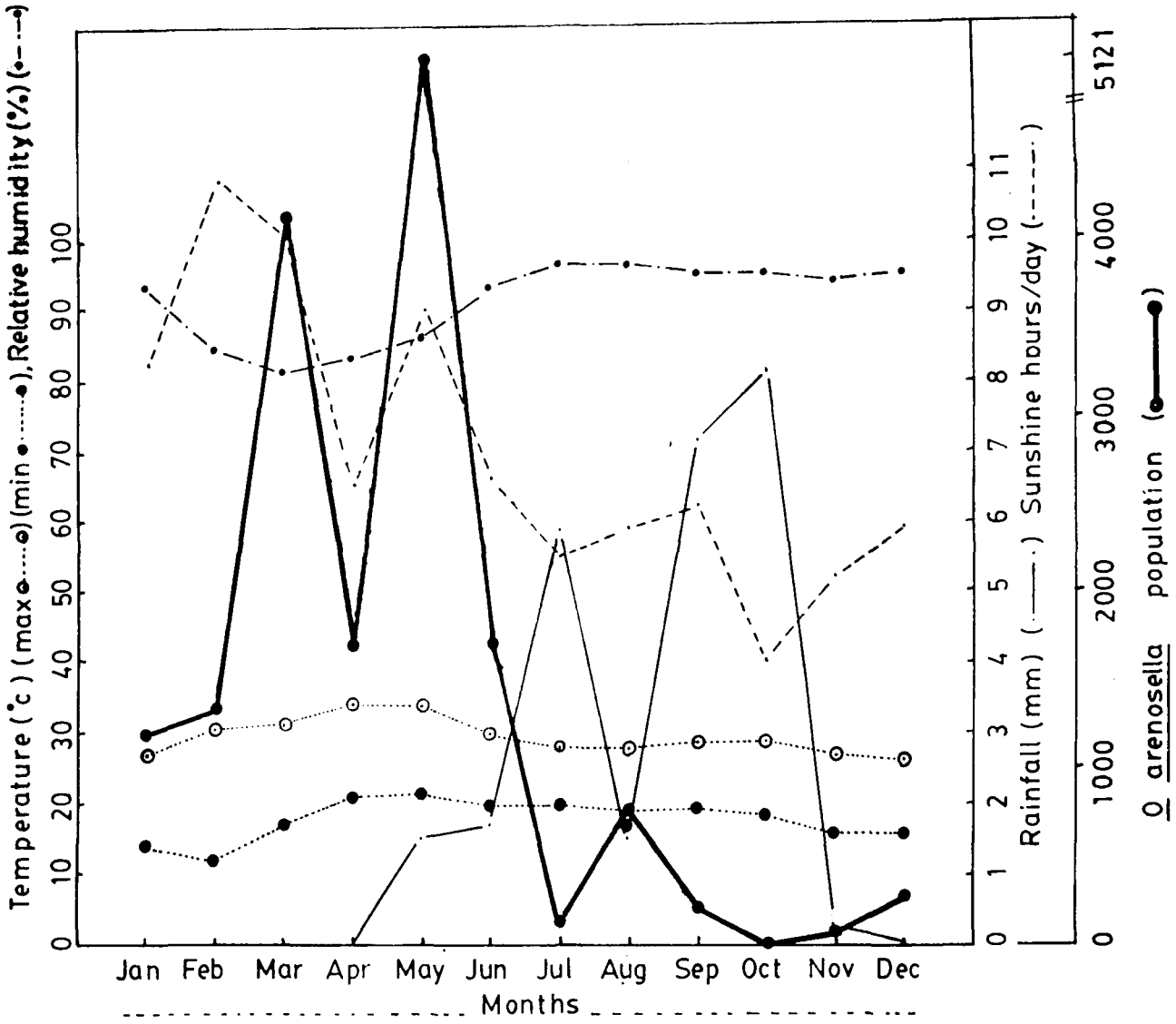


Fig. 1. Population fluctuation of Opisina arenosella in relation to environmental factors.

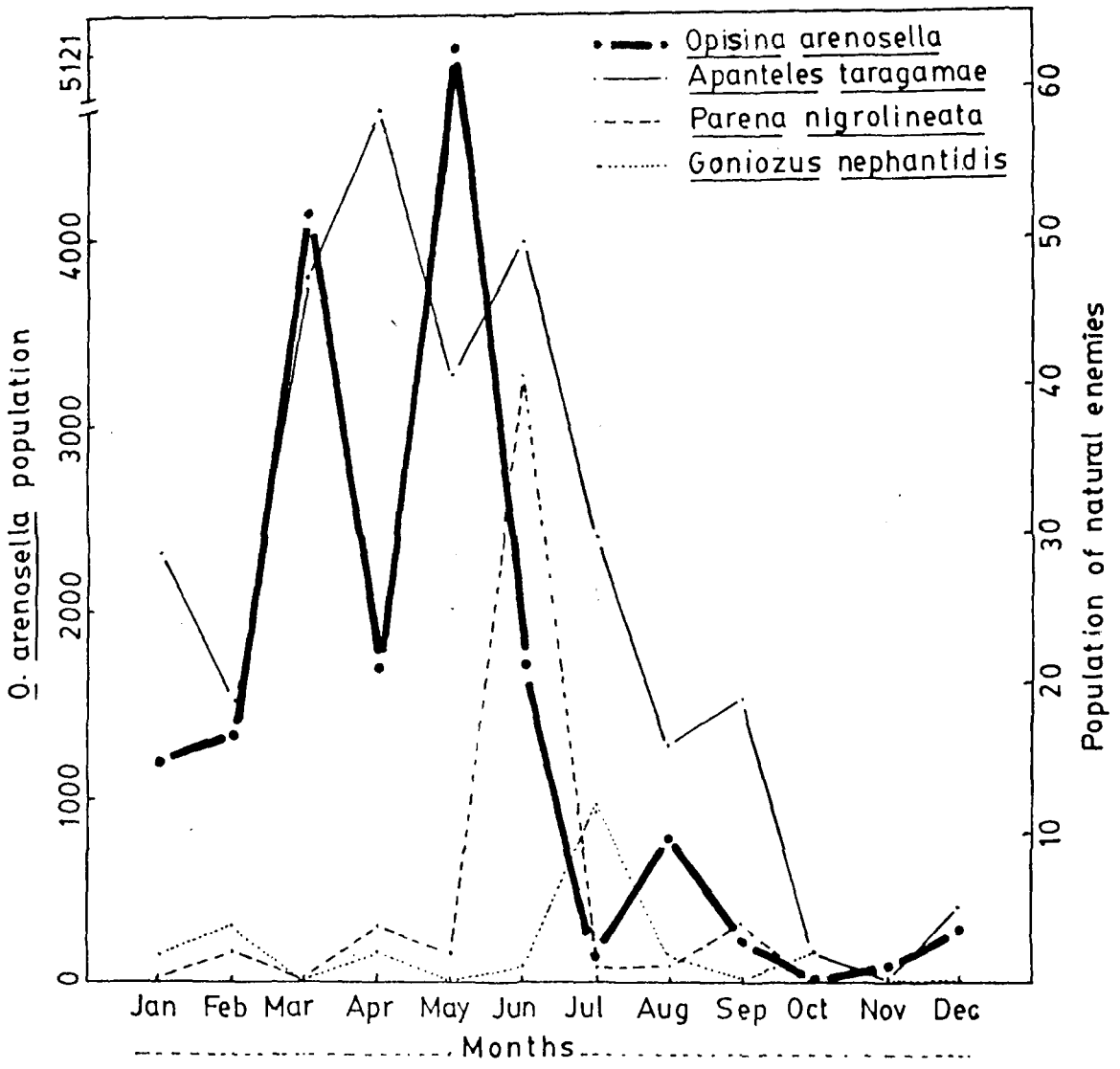


Fig.2. Population fluctuation of Opisina arenosella in relation to biotic factors

was also low (271). In the month of May when the population was at its peak (5121), the maximum mean temperature was 33.9°C. The minimum mean temperature was very low in November (16.00°C) when the population was also low, i.e. 92. The minimum mean temperature (21.40) was observed highest in May when the population was at its peak.

During May when the pest population was at its peak the mean relative humidity was 86 per cent. Low populations of 26 was observed during the month of October, when the mean relative humidity was almost its peak (95.00%).

The average sunshine (hours per day) was the lowest (4.00 hrs/day) in October when the pest population was also at its minimum. In May when the pest population was highest, the average sunshine was 9 hours/day.

The total population of G. nephantidis was independent of the host population. It was absent in the month of May, when host population was at its peak. Only two G. nephantidis was observed in the month of October when the host population was minimum. However, it was at its peak during July.

The population of another parasitoid, A. taragamae was present throughout the year except in the month of November. A maximum of 59 A. taragamae was observed in the month of April when the host population was substantial (1688). In the month of May when the host population was at its peak, A. taragamae was also quite high (41.00). Similarly during October when host population was least, A. taragamae population was also low (2.00).

The carabid was not found in January, March and from October to December and a maximum of 41 carabid beetles were observed in the month of June. The population of carabid predator was observed to be independent of the host. During May there were only two beetles and during October it was nil.

Table 2 presents the correlation matrix between O. arenosella population and abiotic and biotic environmental factors.

O. arenosella population showed low negative correlation (r = -0.394) with mean rainfall and G. nephantidis (r = -0.309). However, O. arenosella population indicated significant high negatively correlation (r= -0.743) with mean relative humidity.

Table 2: Correlation matrix between *O. arenosella* population, environmental factors and natural enemies (Nagenahally, 1989)

	Mean rainfall (mm) X_1	Mean Maximum temperature X_2	Mean Minimum temperature X_3	Mean relative humidity(%) at 0720 X_4	Mean sunshine (hours/day) X_5	*G. nephantidis* Population X_6	*A. taragamae* Population X_7	*P. nigrolineata* Population X_8	*O. arenosella* Population Y
X_1	1.0000								
X_2	-0.1840	1.0000							
X_3	0.3914	0.4766	1.0000						
X_4	0.5079	-0.8115	0.0622	1.0000					
X_5	-0.5553	0.4695	-0.3914	-0.7711	1.0000				
X_6	0.3247	-0.1552	0.0471	0.1992	-0.1285	1.0000			
X_7	-0.2866	0.7533	0.4532	-0.6127	0.4367	0.0579	1.0000		
X_8	-0.0280	0.1566	0.2764	0.0778	-0.0437	-0.1017	0.4380	1.0000	
Y	-0.3939	0.7639**	0.2349	-0.7426**	0.7049*	-0.3091	0.6386*	0.0732	1.0000

** - Significant at 1%
* - Significant at 5%

The value coefficient of determination (r^2) being 0.5515 explained 55.15 per cent fluctuation in O. arenosella population.

Positive and highly significant correlation (r = 0.764) was observed between O. arenosella and mean maximum temperature and the coefficient of determination was 0.584.

Similarly positive correlation of mean sunshine (r = 0.705) and A. taragamae (r = 0.639) with O. arenosella was noticed. The coefficient of determination was 0.497 and 0.408 for mean sunshine and A. taragamae respectively.

Positive but non-significant correlations were noticed between O. arenosella and mean minimum temperature (r = 0.235), and P. nigrolineata (r = 0.073).

4.2 INTRA-TREE SPATIAL DISTRIBUTION OF O. arenosella

Tables 3 and 4 present the data on various statistical parameters viz., mean ($\bar{x}$), variance (s^2), variance mean ratio ($s^2/\bar{x}$), mean crowding (x^*), Lloyd's index of patchiness, k value, chi-square value, degrees of freedom, probability of fit and mean clump size (λ) of intra-tree spatial distribution.

a. Distribution during peak infestation period

Table 3 presents the various parameters for spatial distribution during peak infestation period. The variance values ranged from 0.75 to 25.40 in the different trees and were higher than their respective mean values in all the cases. It increased with increase in mean value. The variance to mean ratio ranged from 1.06 to 5.62. The mean crowding values (0.79 to 9.10) were greater than and linearly related to the mean density values (0.66 to 5.41). Iwao's patchiness regression was calculated as $X^{*} = -0.712 + 1.933\ \bar{x}$. The index of basic Contagion α was less than zero. Density Contagiousness coefficient β was 1.933 which is more than unity.

The values of Lloyd's index of patchiness, an index of dispersion, ranged from 1.06 to 2.33. The exponent k, which is a measure of the amount of clumping ranged from 0.75 to 16.27. In 14 cases the value of k was less than two and more than two in 11 cases. The chi-square values ranged from 0.44 to 43.15 and the probability of fit for negative binomial varied from < 0.001 to 0.80. The mean clump size (λ) ranged from 0.41 to 3.33, being more than two in 11 cases and less than two in 14 cases.

Table 3: Intra-tree spatial distribution of *O. arenosella* during peak infestation period

Tree No.	Mean ($\bar{x}$)	Variance (s^2)	Variance mean ratio ($s^2/\bar{x}$)	Mean crowding (x^*)	Lloyd's index of patchiness	k value	Chi-square (X^2)	D.F.	Probability of fit for negative binomial	Mean c siz (λ
1.	4.74	21.60	4.56	8.30	1.75	1.33	22.16	19	0.25	2.9
2.	2.77	12.92	4.67	6.44	2.33	0.75	18.94	15	0.20	1.7
3.	3.87	19.68	5.09	7.96	2.06	0.94	43.15	24	0.01	2.3
4.	2.86	9.45	3.31	5.16	1.81	1.24	10.66	12	0.55	1.7
5.	3.20	11.89	3.72	5.92	1.85	1.18	26.06	19	0.15	1.9
6.	4.49	17.90	3.98	7.48	1.66	1.50	32.62	20	0.04	2.7
7.	4.24	22.18	5.23	8.47	2.00	1.00	19.86	21	0.50	2.6
8.	2.17	3.40	1.57	2.74	1.26	3.80	10.05	7	0.20	1.3
9.	1.24	1.51	1.22	1.46	1.17	5.69	5.66	4	0.25	0.7
10.	3.76	7.48	1.99	4.75	1.26	3.80	91.15	17	NO.001	2.3
11.	0.66	0.75	1.13	0.79	1.21	4.84	10.31	3	0.02	0.4
12.	4.97	21.78	4.38	8.35	1.68	1.47	23.10	25	0.50	3.06
13.	5.41	25.40	4.70	9.10	1.68	1.46	25.60	22	0.30	3.33
14.	4.81	22.02	4.58	8.39	1.74	1.34	34.75	17	0.01	2.96
15.	4.48	23.58	5.26	8.74	1.95	1.05	34.96	20	0.02	2.76
16.	3.68	20.69	5.62	8.30	2.25	0.80	61.49	28	NO.001	2.26
17.	3.37	8.70	2.58	4.95	1.47	2.12	16.49	14	0.30	2.07
18.	3.01	8.49	2.82	4.83	1.61	1.65	30.60	13	0.01	1.85
19.	2.78	8.49	3.05	4.83	1.74	1.36	13.01	11	0.30	1.71
20.	0.97	1.02	1.06	1.03	1.06	16.27	3 62	4	0.50	0.60
21.	2.21	3.54	1.60	2.81	1.27	3.65	7.63	8	0.50	1.36
22.	2.34	2.71	1.16	2.50	1.07	14.72	10.48	6	0.10	1.44
23.	1.65	2.80	1.70	2.35	1.42	2.36	14.36	7	0.05	1.01
24.	1.16	1.70	1.46	1.62	1.40	2.49	9.40	6	0.15	0.71
25.	0.47	0.50	1.06	0.53	1.13	7.90	0.44	2	0.80	0.29

The variance to mean ratio, mean crowding to mean density and the Lloyd's index of patchiness were greater than one revealing the contagious nature of O. arenosella distribution within the coconut tree.

b. Distribution during lean infestation period

The various statistical parameters of intra trees spatial distribution for low infestation period are presented in Table 4. The population mean was very low and ranged from 0.03 to 0.33. Except in two cases, the variance was greater than the mean. The variance ranged from 0.07 to 0.51. The variance to mean ratio was greater than unity in all but two cases indicating contagious nature of distribution pattern. In the two exceptional cases it was as high as 0.98 and 0.91. Again the mean crowding values were greater than the mean, except for the two trees, indicating the aggregating type of distribution of O. arenosella within a coconut tree. Lloyd's index of patchiness was more than unity in all but two cases. It ranged from 0.54 to 60.62 which indicated aggregation of O. arenosella within a coconut tree.

The exponent k ranged from -8.02 to 2.16. The chi-square values ranged from -0.001 to 13.71 and

Table 4: Intra-tree spatial distribution of *O. arenosella* during lean infestation period

Tree No.	Mean ($\bar{x}$)	Variance (s^2)	Variance mean ratio ($s^2/\bar{x}$)	Mean crowding (x^*)	Lloyd's index of patchiness	k value	Chi-square (X^2)	D.F.	Probability of fit for negative binomial	Mean cl size (λ)
1.	0.22	0.24	1.10	0.32	1.46	2.16	2.78	2	0.25	0.09
2.	0.14	0.14	0.98	0.12	0.89	-	0.04	1	0.85	0.06
3.	0.07	0.12	1.60	0.68	9.07	0.12	3.15	2	0.20	0.03
4.	0.18	0.17	0.91	0.10	0.54	-	-0.001	1	0.95	0.07
5.	0.09	0.10	1.10	0.19	2.08	0.92	0.13	1	0.75	0.04
6.	0.33	0.51	1.53	0.86	2.59	0.63	3.34	2	0.20	0.14
7.	0.22	0.33	1.45	0.68	3.02	0.49	2.34	2	0.30	0.09
8.	0.18	0.27	1.46	0.65	3.54	0.39	0.90	2	0.65	0.07
9.	0.18	0.33	1.83	1.01	3.54	0.22	4.26	2	0.10	0.07
10.	0.22	0.34	1.56	0.78	3.61	0.38	5.13	2	0.07	0.09
11.	0.03	0.05	1.48	0.51	15.37	0.07	0.76	1	0.40	0.01
12.	0.12	0.16	1.28	0.41	3.28	0.44	1.39	1	0.25	0.05
13.	0.18	0.25	1.37	0.56	3.04	0.49	0.41	2	0.80	0.07
14.	0.10	0.19	1.92	1.02	10.16	0.11	3.01	2	0.20	0.04
15.	0.07	0.33	4.97	4.04	60.62	0.02	13.71	5	0.02	0.03
16.	0.05	0.11	2.30	1.35	27.05	0.04	2.61	2	0.30	0.02
17.	0.06	0.07	1.24	0.30	5.07	0.24	0.29	1	0.60	0.02

probability of fit from 0.02 to 0.95. Iwao's (1968) patchiness regression was calculated as $X^* = 1.135 - 2.342\ \bar{x}$. The mean clump size (λ) was less than two in all cases indicating the aggregated nature of the pest to be due to environmental heterogenity. It ranged from 0.01 to 0.14.

4.3 INTER-TREE DISTRIBUTION OF O. arenosella

The data on inter-tree spatial distribution of O. arenosella studied in two seasons during 1989 have been presented in Tables 5 and 6.

a. Distribution during peak infestation period

Table 5 presents the studies on inter-tree spatial distribution of O. arenosella during peak infestation period. The variance mean ratio (4.66) which was more than one indicated the aggregating nature of O. arenosella in coconut trees. Over dispersion pattern of the pest was revealed by the mean crowding (6.70) which exceeded the mean (3.03). Similarly the Lloyd's index of patchiness (2.21) being more than unity indicated aggregated pattern of O. arenosella. The exponent k value was 0.83 and the chi-square value was 92.32 with the probability of fit for negative binomial distribution being less than .001. The value (1.96)

Table 5: Inter-tree spatial distribution of *O. arenosella* during peak infestation period

Sl. No.	Class	Observed frequency	Expected frequency (Negative binomial)
1.	0-0	795	880.050
2.	1-1	808	672.561
3.	2-2	529	508.608
4.	3-3	405	383.265
5.	4-4	280	288.300
6.	5-5	202	216.635
7.	6-6	124	162.668
8.	7-7	102	122.084
9.	8-8	74	91.590
10.	9-9	48	68.692
11.	10-10	38	51.507
12.	11-11	47	38.613
13.	12-12	31	28.943
14.	13-13	25	21.691
15.	14-14	21	16.255
16.	15-15	14	12.179
17.	16-16	12	9.125
18.	17-17	9	6.836
19.	18-18	8	5.121
20.	19-19	5	3.836
21.	20-20	10	2.873
22.	21-22	5	3.764
23.	23-51	8	4.805

Mean ($\bar{x}$)	: 3.035	k value	: 0.829
Variance (s^2)	: 14.147	Chi-square(χ^2)	: 92.321
Variance mean ratio ($s^2/\bar{x}$)	: 4.661	D.F.	: 20
Mean crowding(x^*)	: 6.696	Probability of fit	: Ñ0.001
Lloyd's index of patchiness	: 2.206	Mean clump size(λ)	: 1.956

was less than two, indicating that the aggregation is due to environmental heterogenity.

b. Distribution during low infestation period

Data on inter-tree spatial distribution of O. arenosella during low infestation period are presented in Table 6. The variance to mean ratio was more than unity (1.50) indicating a contagious nature in low infestation season. The mean crowding (0.60) was greater than the mean (0.09) indicating over dispersion. Lloyd's index of patchiness (6.32) was more than one, once again suggesting the aggregated nature of O. arenosella in coconut trees. The k value was 0.19 and chi-square value was 0.96 with probability of fit being 0.35. The value (0.043) was less than two which suggested environmental factors to be responsible for the aggregating behaviour of O. arenosella.

4.4 DISTRIBUTION OF O. arenosella IN RELATION TO DIFFERENT QUADRANTS

a. Distribution during peak population season:

Table 7 presents the data on the distribution of O. arenosella population in coconut trees in relation to directional quadrants during peak infestation period. Of the twenty trees, all but two trees showed significant

Table 6: Inter-tree spatial distribution of *O. arenosella* during lean infestation period

Sl. No.	Class	Observed frequency	Expected frequency (Negative binomial)
1.	0-0	3338	3337.567
2.	1-1	200	205.086
3.	2-2	48	42.307
4.	3-7	14	15.309

Mean ($\bar{x}$)	: 0.095	k value	: 0.188
Variance (s^2)	: 0.142	Chi-square(χ^2)	: 0.964
Variance, mean ratio ($s^2/\bar{x}$)	: 1.504	D.F.	: 1
		Probability of fit	: 0.35
Mean crowding(x^*)	: 0.599	Mean clump size(λ)	: 0.043
Lloyd's index of patchiness	: 6.320		

Table 7: Distribution of *O. arenosella* in individual coconut trees in relation to directional quadrants during peak infestation period

Direction	Average *O. arenosella* population per leaflet in different trees																			
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
North upper	7.53	3.60	5.60	6.53	0.47	5.53	1.20	0.20	2.33	4.40	0.93	4.13	2.00	1.40	1.80	1.67	0.73	0.93	0.60	1.73
North lower	3.27	0.00	2.93	1.13	2.20	1.73	5.40	3.27	2.07	3.87	0.93	1.87	2.40	1.33	5.07	2.13	0.60	0.33	0.87	1.67
South upper	8.93	0.00	2.20	4.40	1.67	7.07	5.73	0.07	2.73	3.73	1.67	1.53	0.93	1.60	0.73	0.53	0.00	0.67	0.87	1.13
South lower	0.00	0.47	2.20	1.87	4.67	0.60	4.53	3.53	1.53	2.33	1.27	3.53	1.80	0.87	2.80	1.47	0.27	0.80	0.93	1.27
East upper	5.40	6.93	8.47	3.73	2.47	1.40	0.80	7.27	2.53	3.53	1.13	2.47	2.13	2.87	1.93	1.27	0.33	0.13	0.87	1.47
East lower	4.67	3.00	2.07	2.47	2.47	3.13	6.20	6.73	3.53	3.53	1.47	1.60	3.27	2.27	1.53	0.73	0.20	0.80	0.40	0.13
West upper	4.73	5.60	5.87	2.47	2.20	3.67	4.73	8.00	1.80	4.93	1.07	1.47	2.80	1.87	0.47	0.13	0.73	0.73	1.60	1.27
West lower	3.40	2.53	1.60	0.27	1.67	2.47	7.33	4.87	0.80	3.73	2.20	1.07	3.40	1.00	1.93	1.33	0.93	0.87	1.60	1.27
S.Em ±	1.03	0.70	1.00	0.65	0.55	0.74	0.96	0.99	0.44	0.70	0.33	0.42	0.39	0.41	0.49	0.31	0.17	0.22	0.25	0.30
CD 5%	2.86	1.95	2.79	1.80	1.53	2.05	2.67	2.76	1.23	NS	0.90	1.16	1.08	1.14	1.37	0.85	0.47	NS	0.68	0.84

NS - Non significant

differences in mean O. arenosella population density in different directional quadrants. In the trees that showed significant differences in population in different directional quadrants, the highest population was in WL region in five trees, NU and EU in three trees each, in NL, SU and WU in two trees each and in SL and EL in one tree each. Minimum population of larvae was in SU region in four trees, in SL, WU and WL in three trees each, in NU, NL, and EL in two trees each and in EU region in one tree.

The distribution of O. arenosella population in relation to directional quadrants in twenty trees taken together is presented in Table 8. There was no significant difference in the average O. arenosella population in the eight quadrants.

O. arenosella population in quadrants NU, EU, EL, WU, and WL were highly correlated with the total tree population. Significant correlation coefficients were observed in NL and SU with the total tree population. Only the quadrant SL was not correlated with total tree population.

b. Distribution during low infestation season

Distribution of O. arenosella in coconut trees in

Table 8: Distribution of O. arenosella population in relation to directional quadrants in peak population infestation (pooled)

Direction	Average O. arenosella population per leaflet	Correlation with total tree population (r)
North upper	3.44	0.72**
North lower	2.38	0.56*
South upper	2.96	0.63*
South lower	2.21	0.39
East upper	3.35	0.64**
East lower	2.92	0.81**
West upper	3.74	0.84**
West lower	3.29	0.72**
CD 5%	NS	

NS - Non significant
* - Significant at 5%
** - Significant at 1%

relation to eight quadrants during low infestation period is presented in Table 9. Except for one tree, the remaining trees showed no significant difference in the mean population level in different quadrants. The tree with significant difference had the highest population in SU region (1.19) and the lowest population in the EU region (1.00). The mean population per leaflet ranged from 1.00 to 1.19.

Table 10 shows the distribution of O. arenosella in relation to directional quadrants in low infestation season when 20 trees were taken together. There was no significant difference in the mean population level in the eight quadrants. The mean population of all but NL and WL quadrants were significantly correlated with the total population.

4.5 DISTRIBUTION OF O. arenosella IN RELATION TO FOUR DIRECTIONAL QUADRANTS

The canopy of the tree was divided into four directional quadrants viz., North, South, East and West.

a. Distribution during peak infestation period

Table 11 shows the distribution of O. arenosella in relation to directional quadrants during peak infestation period. Of the 20 trees observed, 14 had

Table 9: Distribution of O. arenosella in individual coconut trees in relation to directional quadrants during low infestation period

Direction	Average O. arenosella population per leaflet in different trees																			
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
North upper	1.11	1.00	1.00	1.11	1.03	1.10	1.05	1.08	1.03	1.12	1.00	1.00	1.00	1.03	1.00	1.03	1.00	1.00	1.00	1.00
North lower	1.14	1.03	1.00	1.03	1.03	1.11	1.10	1.05	1.00	1.05	1.00	1.05	1.13	1.03	1.11	1.00	1.05	1.05	1.00	1.09
South upper	1.11	1.05	1.03	1.19	1.00	1.20	1.08	1.03	1.08	1.05	1.00	1.03	1.00	1.00	1.05	1.00	1.03	1.00	1.00	1.00
South lower	1.05	1.00	1.00	1.05	1.10	1.09	1.08	1.03	1.00	1.05	1.08	1.10	1.17	1.11	1.00	1.00	1.03	1.05	1.03	1.00
East upper	1.05	1.13	1.03	1.00	1.03	1.22	1.17	1.03	1.19	1.14	1.00	1.00	1.05	1.00	1.00	1.05	1.00	1.00	1.03	1.00
East lower	1.11	1.11	1.05	1.03	1.05	1.10	1.05	1.22	1.10	1.05	1.00	1.13	1.03	1.10	1.00	1.03	1.05	1.00	1.00	1.00
West upper	1.08	1.05	1.00	1.05	1.00	1.12	1.05	1.05	1.05	1.15	1.00	1.00	1.10	1.03	1.00	1.00	1.00	1.03	1.05	1.00
West lower	1.03	1.08	1.12	1.14	1.05	1.05	1.10	1.08	1.09	1.03	1.03	1.08	1.08	1.00	1.00	1.05	1.03	1.05	1.03	1.05
S.Em ±	0.05	0.04	0.03	0.04	0.03	0.07	0.05	0.05	0.05	0.05	0.02	0.04	0.05	0.04	0.04	0.02	0.02	0.03	0.02	0.03
CD 5%	NS	NS	NS	0.11	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	17.55	14.01	12.10	14.86	12.19	23.20	19.86	17.65	19.25	19.97	8.24	14.46	17.23	15.10	16.12	8.85	9.57	10.34	8.19	11.51

NS - Non significant

Table 10: Distribution of O. arenosella population in relation to directional quadrants in low population infestation (pooled)

Direction	Average O. arenosella population per leaflet	Correlation with total tree population (r)
North upper	0.10	0.71**
North lower	0.14	0.45
South upper	0.12	0.77**
South lower	0.13	0.47
East upper	0.14	0.77**
East lower	0.14	0.53*
West upper	0.11	0.80**
West lower	0.13	0.48
CD 5%	NS	

NS - Non significant
* - Significant at 5%
** - Significant at 1%

Table 11: Distribution of *O. arenosella* in individual coconut trees in relation to directional quadrants during peak infestation period

Direction	Average *O. arenosella* population per leaflet in different trees																			
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
North	5.40	1.80	4.27	3.83	1.33	3.63	3.30	1.73	2.20	4.13	0.93	3.00	2.20	1.37	3.43	1.90	0.67	0.63	0.73	1.70
South	4.47	0.23	2.20	3.13	3.17	3.83	5.13	1.80	2.13	3.03	1.47	2.53	1.37	1.23	1.77	1.00	0.13	0.73	0.90	1.20
East	5.03	4.97	5.27	3.10	2.47	2.27	3.50	7.00	3.03	3.53	1.30	2.03	2.70	2.57	1.73	1.00	0.27	0.47	0.63	0.80
West	4.07	4.07	3.73	1.37	1.93	3.07	6.03	6.43	1.30	4.33	1.63	1.27	3.10	1.43	1.20	0.73	0.83	0.80	1.60	1.27
S.Em ±	0.86	0.57	0.79	0.54	0.42	0.63	0.75	0.74	0.32	0.50	0.23	0.33	0.28	0.29	0.39	0.23	0.12	0.16	0.17	0.22
CD 5%	NS	1.57	NS	1.50	1.16	NS	2.09	2.05	0.89	NS	NS	0.91	0.78	0.81	1.09	0.63	0.33	NS	0.48	0.61

NS - Non significant

significant differences in mean population amongst directional quadrants. Five trees had maximum mean population of O. arenosella in the North region, four trees each in the East and West region and only one tree in the South region. Minimum mean larval population was present in the West region in five trees and in the North, South and East region in three trees each.

Data on the distribution of O. arenosella population when 20 trees are taken together are presented in Table 12. There were no significant differences in the average population of larvae in different quadrants. However, highly significant correlation between each quadrant counts and total tree population was observed.

b. Distribution during low infestation period:

Data on the distribution of O. arenosella in 20 coconut trees in relation to directional quadrants during low infestation period are presented in Table 13. Only one tree showed significant difference in the mean O. arenosella population in different quadrants. In this tree, the mean showed a range from 1.01 larvae per leaflet in the North region to 1.12 in the East region.

Table 12: Distribution of O. arenosella population in relation to directional quadrants in peak population infestation (pooled)

Direction	Average O. arenosella population per leaflet	Correlation with total tree population (r)
North	2.91	0.82**
South	2.59	0.73**
East	3.13	0.83**
West	3.52	0.87**
CD 5%	NS	

NS - Non significant
* - Significant at 5%
** - Significant at 1%

Table 13: Distribution of O. arenosella in individual coconut trees in relation to directional quadrants during low infestation period

Direction	Average O. arenosella population per leaflet in different trees																			
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
North	1.13	1.01	1.00	1.07	1.03	1.11	1.08	1.06	1.01	1.09	1.00	1.02	1.06	1.03	1.05	1.01	1.03	1.03	1.00	1.05
South	1.08	1.03	1.01	1.12	1.05	1.15	1.08	1.03	1.04	1.05	1.04	1.06	1.08	1.06	1.02	1.00	1.03	1.02	1.01	1.00
East	1.08	1.12	1.04	1.01	1.04	1.16	1.11	1.12	1.14	1.09	1.00	1.06	1.04	1.05	1.00	1.04	1.03	1.00	1.01	1.00
West	1.05	1.07	1.06	1.10	1.03	1.09	1.07	1.07	1.07	1.09	1.01	1.04	1.09	1.01	1.00	1.03	1.01	1.04	1.04	1.02
S.Em ±	0.03	0.03	0.02	0.03	0.02	0.05	0.04	0.03	0.04	0.04	0.01	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.02
CD 5%	NS	0.07	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	17.41	13.87	12.31	15.20	12.34	23.13	19.77	17.96	19.17	20.04	8.35	14.86	17.71	15.31	16.12	8.86	9.62	10.35	8.14	11.62

NS - Non significant

Table 14 shows the distribution of O. arenosella, when the 20 trees are taken together. The mean O. arenosella population in different quadrants, were not significantly different but a significant correlation of each quadrant with total tree population was observed.

4.6 DISTRIBUTION OF O. arenosella IN RELATION TO TREE CANOPY HEIGHT

The canopy of the tree was divided into upper and lower level.

a. Distribution during peak infestation period

The data on the distribution of O. arenosella during March to May, in relation to tree height are presented in Table 15. Of the 20 trees observed, only nine trees had significant differences in the mean population between two heights. Seven trees had the highest mean O. arenosella population in the upper level while two trees showed highest mean in the lower level.

Table 16 presents the data on distribution of O. arenosella population in different levels of the coconut tree in peak infestation period when the data from 20 trees were taken together. There was no

Table 14: Distribution of *O. arenosella* population in relation to directional quadrants in low population period (pooled)

Direction	Average *O. arenosella* population per leaflet	Correlation with total tree population (r)
North	0.12	0.70**
South	0.12	0.81**
East	0.14	0.82**
West	0.12	0.85**
CD 5%	NS	

NS - Non significant
** - Significant at 1%

Table 15: Distribution of *O. arenosella* in individual coconut trees in relation to tree height during peak infestation period (March to May 89)

Crown Level	Average *O. arenosella* population per leaflet in different trees																			
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
Upper	11.65	6.03	6.53	4.28	3.70	12.42	10.12	4.88	5.35	9.15	3.20	4.40	4.97	2.93	2.23	1.90	1.45	1.62	1.98	4.40
Lower	2.83	1.50	2.20	1.43	2.75	1.98	5.87	4.60	1.98	3.37	1.47	2.02	2.72	1.37	2.83	1.42	0.50	0.70	0.95	1.08
S.Em ±	0.55	0.43	0.53	0.35	0.30	0.42	0.52	0.61	0.24	0.35	0.17	0.24	0.21	0.21	0.28	0.16	0.09	0.11	0.13	0.16
CD 5%	2.00	1.59	1.94	1.28	NS	1.52	1.89	NS	NS	NS	NS	NS	0.58	NS	0.77	0.46	NS	NS	NS	NS
CV%	89.66	122.03	106.70	95.59	103.67	101.20	89.41	111.19	85.04	72.31	96.79	85.16	68.78	100.37	106.09	110.69	149.93	131.76	105.11	98.63

NS - Non significant

Table 16: Distribution of O. arenosella population in different canopy levels of coconut trees in peak infestation period (March to May 89)

Crown Level	Average O. arenosella population per leaflet	Correlation with total tree population (r)
Upper	3.37	0.91**
Lower	2.70	0.85**
F test	NS	
C.V.%	55.96	

NS - Non significant
** - Significant at 1%

significant difference in the mean O. arenosella population in the upper and lower levels of the tree. There was significant correlation of the two levels with total tree population.

b. Distribution during low infestation period

Table 17 shows the data on distribution of O. arenosella during September to November in relation to tree height when the infestation was low. All the twenty trees had the higest mean O. arenosella population per leaflet in the upper level. Of the 20 trees surveyed, only two trees showed significant differences at 5 per cent in the mean O. arenosella population.

The data on mean O. arenosella population in relation to tree height when the distribution in 20 trees were taken together during the lean infestation period are presented in Table 18. There was no significant difference in the mean O. arenosella population in the upper and lower levels of the tree. There was significant correlation of the population in the different levels with the total population of the tree.

Table 17: Distribution of *O. arenosella* in individual coconut trees in relation to tree height during low infestation period (September to November 89)

Crown Level	Average *O. arenosella* population per leaflet in different trees																			
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
Upper	2.09	2.06	2.01	2.09	2.01	2.16	2.09	2.05	2.09	2.12	2.00	2.01	2.04	2.01	2.01	2.02	2.01	2.01	2.02	2.00
Lower	1.08	1.05	1.04	1.06	1.06	1.09	1.08	1.09	1.05	1.04	1.03	1.09	1.10	1.06	1.03	1.02	1.04	1.04	1.01	1.03
S.Em ±	0.024	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
CD 5%	NS	NS	NS	NS	0.04	NS	NS	NS	NS	NS	NS	0.05	NS	NS	NS	NS	NS	NS	NS	NS
CV%	17.42	14.32	12.33	15.48	12.07	22.86	19.65	17.96	19.48	19.63	8.32	14.26	17.40	15.10	16.12	8.92	9.41	10.24	8.20	11.55

NS - Non significant

4.7 DISTRIBUTION OF O. arenosella IN RELATION TO FROND POSITION ON TRUNK

The data on average O. arenosella population per leaflet in different fronds, marked from the base of the crown of the tree to the apex, is presented in Table 19. There was significant difference in mean O. arenosella population in different fronds. In the five trees observed, the least population was in the 5th frond from the base in four trees and in the 1st frond from the base in one tree. The maximum population was in the 15th frond from the base in four trees and in the 10th frond from the base in one tree, but this was on par with 15th frond. Overall, the population of the pest was low in the lower fronds and significantly more in the upper fronds.

4.8 DISTRIBUTION OF O. arenosella POPULATION WITHIN A FROND

The data on distribution of O. arenosella in three frond regions are presented in Table 20. There were no significant differences in the mean O. arenosella population in different regions in the 1^{st}, 10^{th}, and 15^{th} frond from the base of the crown. Only the 5^{th} frond from the base showed significant difference in the

Table 18: Distribution of O. arenosella population in different canopy levels of coconut trees in low infestation period (September to November 89)

Crown Level	Average O. arenosella population per leaflet	Correlation with total tree population (r)
Upper	0.12	0.91**
Lower	0.13	0.80**
F test	NS	
C.V.%	62.76	

NS - Non significant
** - Significant at 1%

Table 19: Distribution of O. arenosella population in relation to frond position on the trunk

Frond position from base	Average O. arenosella population per leaflet in different trees				
	1	2	3	4	5
1st frond	0.067	0.067	0.633	0.233	0.233
5th frond	0.100	0.033	0.067	0.000	0.067
10th frond	0.100	1.033	1.000	0.167	0.567
15th frond	0.833	0.767	1.400	1.400	0.600
S.Em ±	0.095	0.160	0.202	0.146	0.120
F test	0.263	0.444	0.560	0.406	0.332

distribution of larvae in different regions. No O. arenosella was present in the middle and apex region and a very low population of 0.16 larva per leaflet was present in the basal region of the frond.

4.9 DISTRIBUTION OF O. arenosella WITHIN A LEAFLET

The data on distribution of O. arenosella within a leaflet in different parts as well as entire leaflet are presented in Table 21. The mean density varied from 0.21 to 0.57, the maximum being in the middle portion and the least in the apical portion. The variance ranged from 0.19 in the apical portion to 0.41 in the basal portion. Variance to mean ratio was 1.00 in the basal portion indicating random distribution and less than unity in the remaining portions indicating uniform distribution of larvae.

The larval number in the basal region showed significant correlation ($r = 0.460$) with the larval population in the entire leaflet whereas those in the other two regions showed non-significant correlation.

4.10 OPTIMUM NUMBER OF LEAFLETS REQUIRED PER COCONUT TREE FOR ESTIMATING MEAN O. arenosella POPULATION

Table 22 presents the optimum number of leaflets required for estimating the mean density of

Table 20: Distribution of *O. arenosella* population within a frond

Portion of the frond	Mean number of *O. arenosella* per leaflet			
	1st frond	5th frond	10th frond	15th frond
Base	0.30	0.16	0.92	1.06
Middle	0.38	0.00	0.46	1.10
Apex	0.06	0.00	0.34	0.84
S.Em ±	0.13	0.03	0.24	0.27
C.D. 5%	NS	0.09	NS	NS

NS - Non significant

Table 21: Distribution of *O. arenosella* within a leaflet

Regions	Mean Larval number (x)	Variance (s^2)	Variance mean ratio ($s2_{/x}$)	C.V.%	Correlation with population in entire leaflet
Base	0.41	0.41	1.00	156.17	0.46**
Middle	0.57	0.33	0.58	100.78	0.19
Apex	0.21	0.19	0.90	207.57	0.12
Entire leaflet	1.18	0.19	0.16	36.94	

** - Significant at 1%

Table 22: Optimum sample size and stop lines for fixed precision level in peak and lean season

	D	Sample size	Stop lines for fixed precision level (T)
Peak season	0.10	103.22	145462.25
	0.15	45.87	1149.22
	0.25	16.51	2.58
Lean season	0.10	1409.00	221.07
	0.15	626.22	88.34
	0.25	225.44	27.82

O. arenosella at different levels of D viz., 0.10, 0.15, and 0.25.

In the peak season, a sample size of 103, 46 and 16 leaflets are required at precision levels, D = 0.10, 0.15 and 0.25 respectively for estimating the mean population of O. arenosella. Similarly in the lean season 1409, 626 and 225 leaflets per tree are required for estimating the mean population level at D = 0.10, 0.15 and 0.25 precision levels respectively.

The stop lines for fixed precision level during peak season at D = 0.10, 0.15 and 0.25 are 145462, 1149 and 3 respectively. During lean season at D = 0.10, 0.15 and 0.25, it is 221, 88 and 23 respectively.

4.11 APPROPRIATE TRANSFORMATION FOR STABILISING VARIANCE IN O. arenosella POPULATION

To make the variance and mean independent of each other and to normalize the distribution, data are transformed, before being subjected to analysis of variance.

Table 23 shows the mean and variance and the correlation coefficent 'r' between them for twenty sets of data in original and transformed forms. The different

Table 23: Suitability of different transformations for stabilizing O. arenosella population variance

Tree No.	Original Count (x)		$\sqrt{x+1}$		Log(x+1)		Log(x+k)		Log(x+k/2)		Log[Log(x+2)]		$\sinh^{-1}\sqrt{\frac{\beta-1}{\alpha}x+1}$		$x^{1-b/2}$	
	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
1	4.74	21.60	2.20	0.88	1.39	0.82	1.50	0.66	1.24	1.08	0.42	0.23	1.22	0.49	0.96	0.26
2	2.77	12.92	1.75	0.69	0.92	0.80	0.77	1.00	0.42	1.64	0.16	0.24	0.84	0.57	0.70	0.36
3	3.87	19.68	2.03	0.76	1.25	0.66	1.22	0.69	0.99	1.04	0.36	0.18	1.17	0.37	0.99	0.19
4	2.86	9.45	1.82	0.53	1.05	0.63	1.15	0.52	0.84	0.91	0.25	0.19	0.99	0.44	0.85	0.27
5	3.20	11.89	1.91	0.56	1.15	0.59	1.22	0.52	0.94	0.87	0.31	0.17	1.09	0.39	0.92	0.23
6	4.49	17.90	2.18	0.74	1.40	0.67	1.55	0.50	1.31	0.81	0.43	0.18	1.26	0.37	1.03	0.18
7	4.24	22.18	2.08	0.90	1.26	0.84	1.26	0.84	1.00	1.32	0.35	0.23	1.32	0.51	0.92	0.27
8	2.17	3.40	1.70	0.27	0.97	0.40	1.74	0.09	1.30	0.21	0.22	0.13	0.98	0.31	0.88	0.21
9	2.22	5.55	1.71	0.31	0.97	0.39	1.17	0.27	0.84	0.50	0.23	0.12	0.99	0.29	0.90	0.19
10	3.76	7.48	2.11	0.32	1.42	0.28	1.97	0.10	1.64	0.18	0.47	0.07	1.34	0.11	1.14	0.03
11	1.32	1.68	1.47	0.17	0.69	0.32	1.81	0.01	1.27	0.11	0.06	0.12	0.74	0.32	0.71	0.27
12	2.21	3.54	1.72	0.24	1.00	0.33	1.72	0.09	1.30	0.19	0.25	0.10	1.04	0.23	0.95	0.15
13	2.34	2.71	1.77	0.21	1.07	0.29	2.83	0.01	2.26	0.03	0.29	0.09	1.09	0.20	0.99	0.13
14	1.66	2.80	1.55	0.23	0.79	0.37	1.31	0.14	0.88	0.31	0.12	0.13	0.84	0.32	0.79	0.24
15	2.03	5.26	1.65	0.30	0.91	0.38	1.03	0.31	0.71	0.55	0.19	0.12	0.95	0.29	0.88	0.20
16	1.16	1.70	1.41	0.16	0.62	0.29	1.24	0.10	0.76	0.23	0.02	0.11	0.69	0.29	0.69	0.26
17	0.47	0.50	1.18	0.07	0.30	0.17	2.12	0.01	1.47	0.02	-0.17	0.07	0.36	0.23	0.38	0.25
18	0.66	0.75	1.25	0.09	0.40	0.20	1.69	0.02	1.09	0.06	-0.11	0.08	0.48	0.26	0.50	0.27
19	0.97	1.02	1.36	0.17	0.56	0.24	2.84	0.00	2.20	0.01	-0.01	0.09	0.64	0.27	0.65	0.26
20	1.24	1.51	1.44	0.15	0.67	0.28	1.92	0.03	1.37	0.08	0.05	0.10	0.74	0.28	0.73	0.24
r	0.916*		0.850*		0.684*		-0.671*		-0.596*		0.512*		0.187 NS		-0.647*	

* - Significant at 5%
NS - Non significant

transformations applied were $\sqrt{x+1}$, log(x+1), log(x+k), log (x+k/2), log[log(x+2)], Sinh-1 $\sqrt{\frac{\beta - 1}{\alpha + 1}}$ x and $x^{1-b/2}$.

The original count (x), when subjected to correlation analysis, showed a significant positive correlation coefficient of 0.916. The transformations $\sqrt{x+1}$, log(x+1) and log[log(x+2)] showed significant positive correlation coefficients of 0.850, 0.684 and 0.512 respectively.

Singnificant negative correlation coefficient of -0.671, -0.596 and -0.647 were obtained for the transformations log(x+k), log(x+k/2) and $x^{1-b/2}$, respectively.

The transformation Sinh-1 $\sqrt{\frac{\beta - 1}{\alpha + 1}}$ x had a non significant correlation coefficient of 0.187.

4.12 INTERSPECIFIC ASSOCIATIONS AMONG *Opisina arenosella*, *Apanteles taragamae* and *Parena nigrolineata*

The associations among the two natural enemies of coconut black headed caterpillar and the host were studied under natural conditions.

Table 24 presents the means and variances of the data for the three species in the month of June when all the three species were found. In general, the variance exceeded mean in the case of O. arenosella. However, the mean and variance were almost equal for A. taragamae and P. nigrolineata. Table 25 shows the interspecific association based on a 2 x 2 contingency table.

a. Association between O. arenosella and A. taragamae

From the 2 x 2 contingency table, a positive association between the two species was observed. The degree of overlapping (r) is presented in the Table 26.

The degree of overlapping (r) ranged from 0.08 to 0.25 with an average of 0.16.

b. Association between O. arenosella and P. nigrolineata

A positive association between the two species was observed as is evident from the 2 x 2 contingency table (Table 25).

The mean r value was 0.13 with a range of 0.01 to 0.24 (Table. 27) which indicated weak association between the two species.

Table 24: Means and Variances of the counts of O. arenosella, A. taragamae and P. nigrolineata in coconut in June 1989 at Nagenahalli

Tree No.	O. arenosella		A. taragamae		P. nigrolineata	
	Mean	Variance	Mean	Varinace	Mean	Variance
1.	1.7750	2.7977	0.0500	0.0479	0.0083	0.0083
2.	1.3667	1.2426	0.0583	0.0722	0.0250	0.0246
3.	1.0083	1.1680	0.0500	0.0815	0.0083	0.0083
4.	2.9250	7.2632	0.0750	0.0700	0.0750	0.0700
5.	0.8250	0.9187	0.0333	0.0325	0.0083	0.0083
6.	0.6583	0.6806	0.0250	0.0246	0.0417	0.0571
7.	1.4000	1.9899	0.0583	0.0554	0.0583	0.0554
8.	1.3917	1.4167	0.0333	0.0325	0.0500	0.0479
9.	1.2750	1.8481	0.0333	0.0325	0.0583	0.0722
10.	1.5167	2.2686	0.0083	0.0083	0.0167	0.0165
Pooled	1.4142	2.4964	0.0417	0.0450	0.0342	0.0364

Table 25: **Interspecific association based on a 2 x 2 contingency table**

Interspecific association	Components of 2 x 2 contingency table				χ^2	Type of association
	a	b	c	d		
O. arenosella - *A. taragamae*	40	798	8	354	4.3256*	ad¡bc. Positive
O. arenosella - *P. nigrolineata*	32	806	8	354	2.0303	ad¡bc, Positive
P. nigrolineata - *A. taragamae*	2	46	38	1114	0.1077	ad¡bc, Positive

X^2 at 5%, One degree of freedom = 3.84.

Table 26: Spatial association between *Opisina arenosella* and *Apanteles taragamae*

Tree No.	m^{*}_{xy}	m^{*}_{yx}	r	r(ind)
1	0.05	1.67	0.15	0.16
2	0.06	1.43	0.17	0.16
3	0.05	1.00	0.12	0.12
4	0.08	3.33	0.23	0.20
5	0.07	1.75	0.25	0.12
6	0.02	0.67	0.10	0.10
7	0.07	1.71	0.21	0.17
8	0.02	1.00	0.10	0.14
9	0.04	1.75	0.17	0.12
10	0.01	2.00	0.08	0.06
Mean			0.16	

m^{*}_{xy} = mean crowding on species X by species y
m^{*}_{yx} = mean crowding on species Y by species x
r & r(index) = overlapping index

Table 27: Spatial association between *Opisina arenosella* and *Parena nigrolineata*

Tree No.	m^{*}_{xz}	m^{*}_{zx}	r	r(ind)
1	0.02	4.00	0.15	0.07
2	0.05	2.67	0.24	0.12
3	0.01	1.00	0.06	0.06
4	0.04	1.44	0.01	0.02
5	0.01	1.00	0.07	0.06
6	0.05	0.80	0.13	0.11
7	0.08	2.00	0.24	0.17
8	0.05	1.33	0.16	0.17
9	0.07	1.57	0.18	0.14
10	0.01	1.00	0.06	0.09
Mean			0.13	

m^{*}_{xz} = mean crowding on species x by species z
m^{*}_{zx} = mean crowding on species z by species x
r & r(index) = overlapping index

c. Association between *A. taragamae* and *P. nigrolineata*

The 2 x 2 contigency table (Table 25) shows a positive association between the two species. Table 28 presents the spatial association between the two species. The r index, a measure of association in terms of degree of overlapping was 0 in all but two trees. The average r value was 0.05 indicating independent nature of the two species.

Table 28: Spatial association between *Apanteles taragamae* and *Parena nigrolineata*

Tree No.	m^{*} yz	m^{*} zy	r	r(ind)
1	0.00	0.00	0.00	0.02
2	0.00	0.00	0.00	0.03
3	0.00	0.00	0.00	0.01
4	0.11	0.11	0.01	0.01
5	0.25	1.00	0.49	0.02
6	0.00	0.00	0.00	0.03
7	0.00	0.00	0.00	0.06
8	0.00	0.00	0.00	0.04
9	0.00	0.00	0.00	0.04
10	0.00	0.00	0.00	0.01
Mean			0.05	

m^{*} yz = mean crowding on species y by species z
m^{*} zy = mean crowding on species z by species y
r & r(index) = overlapping index

DISCUSSION

V DISCUSSION

Results obtained from the study as per the objectives envisaged are discussed here under.

5.1 SEASONAL POPULATION FLUCTUATIONS OF O. arenosella IN RELATION TO ENVIRONMENTAL FACTORS

The data on population fluctuations of O. arenosella in relation to various environmental factors at Nagenahalli, Bangalore, during the year 1989 showed that the population of O. arenosella tended to reach a peak during March to June, while it showed a decreasing trend during September to December. The highest population was observed in the month of May and the lowest in October. But the pest was present throughout the year. Nadarajan (1977) also noticed the incidence of the pest in Bangalore throughout the year.

There was a significant positive correlation between mean maximum temperature and the population of the pest. During the summer months when the temperature ranged between 30.5 - 34.1^{o}C, the population was high. With the decrease in mean maximum temperature (26.5 - 28.9^{o}C) during the winter months, the population also decreased. Similar trends of increase in its populations

during summer months and decrease during the winter months were observed by Anstead (1928), Nirula (1951a), Narayananan (1954), Baburaya Nayak (1970), Joy and Joseph (1972), Narendran et al., (1978), Ramachandran et al., (1979), Mohamed et al. (1982a). The prevalent temperature during this period (30.5-34.1^{o}C) appears to favour the process of development of the pest and may be unfavourable to the natural enemies aiding in the rapid multiplication of the pest.

Mean relative humidity revealed highly significant negative correlation with the pest population. Mean relative humidity exceeding 93% favours the development of pathogens which inturn reduce the pest population. This is in confirmation with the observations made by Antony and Kurian (1961) who observed a bacterial disease to be active at 95 per cent relative humidity. Mohamed et al. (1982a) suggested that the decrease in population with the onset of monsoon is due to the spread of fungal and bacterial infections. But, Sathiamma et al. (1972) and Ramachandran et al. (1979), found RH to be directly correlated with the population. Narendran et al. (1978) observed the pest population to be high when maximum relative humidity ranged from 65 to 85 per cent. In the present study also pest population

was high when mean relative humidity ranged between 81-86%.

Mean sunshine hours per day is positively correlated with the pest population. More hours of sunshine per day favour the multiplication of the host. When the hours of sunshine per day decrease, the pest population also decreases.

The population of G. nephantidis, the larval parasitoid was generally low and nil in the months of March, September, November and December. This is in contrast to the findings of George et al., (1977), who reported G. nephantidis to be the most efficient larval parasitoid to be present throughout the year and exerting greater check on the pest population. They observed larval parasitism to be highest in September, which is contrary to the present finding. G. nephantidis was in constant association with the host (Nadarajan, 1977) and is the key mortality factor in biological control of O. arenosella (Sundaramurthy and Santhanakrishan, 1979). Peak parasitization by G. nephantidis was observed in May by Vyas and Butani (1986) but in this case it was absent in May. Similarly Kapadia (1987) observed maximum parasitization by

G. nephantidis along with Bracon brevicornis in November and December in Gujarat. Whereas in the present study during this period it was absent.

Apanteles taragamae population was present throughout the year except in the months of November. Nadarajan (1977) also reported the absence of A. taragamae in November, in addition to October, May and June when extreme weather conditions prevailed. But in the present study A. taragamae population was quite high during May and June when the pest population was also quite high. During these months, the pest was in early larval instars and hence the population of A. taragamae, an early larval instar parasitoid, was quite high. Since O. arenosella has overlapping generations, this parasitoid is able to survive throughout the year.

The population of carabid predator P. nigrolineata was quite high during the month of June and was low in February, April, May, July to September while it was absent during January to March and from October to December. As a matter of fact the population of predator was independent of its prey population. Gulagannavar (1984) observed the activity of the predator through out

the year with high population from June to January. Pillai and Kesava Bhat (1987) also observed low population of the beetle during rainy season and recorded an egg parasitoid Xenomerus on P. nigrolineata whose intensity of natural parasitism was quite high during rainy season.

The population of O. arenosella though present all round the year, fluctuates depending upon the abiotic and biotic factors. In the present studies mean maximum temperature and mean sunshine hours showed significant positive correlations and explained the fluctuations in pest population to the extent of 58.35 and 49.68 per cent respectively. The mean relative humidity was negatively correlated and the value of coefficient of determiniation was 0.55 which explained 55.14 per cent fluctuation. In the West coast as the population increases with the advancement of summer, it suddenly comes down because of torrential South west monsoons in June - July. It takes time to develop to pest status after the cessation of rain restricting the peak pest situation to a quarter of an year.

O. arenosella has a number of parasitoids and predators which in turn also depends on the weather

factors for their multiplication in addition to availability of host. For example G. nephantidis is an efficient larval parasitoid, associated with the host throughout the year according to several workers. But in the present study its activity was very much restricted. However G. nephantidis activity is inhibited at higher temperature with restricted humidity. The population of the parasitoid closely follows the pattern of host but, will not be able to cope up with higher temperature, longer sunshine hours when the pest increase phenomenally, on the other hand A. taragamae probably survives better and is more efficient at higher temperature and sunshine thus it is more efficient.

Similarly Parena nigrolineata, although active throughout the year, its population increases during June - December (Gulagannavar, 1984) and its fecundity increases with the increase in relative humidity (Pillai and Kesava Bhat, 1987).

Thus it is seen that O. arenosella occurs through out the year, but the population reaches peak during summer months namely, March to May and remains low during rainy season and winter up to December.

5.2 INTRA-TREE DISTRIBUTION

a. Distribution during peak infestation period

The variance mean ratio which is the simplest index of dispersion, ranged from 1.06 to 5.62 in different trees. The ratio being greater than unity indicated the aggregated nature of O. arenosella. The variance mean ratio has been used widely as convenient criterion in the recent past to study the distribution pattern of insect pest in perennial crops (Tandon, 1985; Verghese et al., 1985; Verghese et al., 1988a and Tandon et al., 1989). This was again confirmed by the mean crowding values which were greater than their respective means. According to Lloyd (1967) mean crowding is a more sophisticated measure of crowding and the parameter can be applied properly only to the freely moving animals. However, Iwao (1968) pointed out that mean crowding is a population parameter that describe and important aspect of spatial relationship among individuals.

The values of Lloyd's (1967) index of patchiness was larger than one in all the trees indicating over-dispersion of O. arenosella population.

Iwao's (1968) patchiness regression fitted between mean and mean crowding was $X^{*} = -0.713 + 1.933\ \bar{x}$. The

index of basic contagion α was less than one and β, the density contagiousness coefficient, was greater than one. The latter indicated that O. arenosella population was distributed contagiously on coconut trees which explains the two different aspects of aggregation pattern viz., whether or not the individuals are distributed in colonies and second whether or not the distribution pattern of such basic units is contagious. In the present case $\alpha > 0$ which explains that loose aggregate of individuals form the basic component of distribution and this is due to the fact that female moth prefer to lay eggs near already infested leaflets and the first instar larvae is found in aggregates. Further $\beta > 1$ revealed that these loose clumbs are further distributed contagiously. Similar observations were made by Iwao (1969) in case of brown plant hopper, Nilaparvata lugens and Tandon (1985) in case of citrus green scale.

The λ value explains the cause of aggregation. It was greater than two in case of 11 trees suggesting the aggregation to be due to environmental and or behavioral factors. In the remaining 14 trees, it was less than two indicating the environmental factors to be responsible for aggregation. The main behavioural components as

responsible for aggregation explained are (i) the habit of adult preferring to lay egg nearer to the old infestation, (ii) the initial congregation of early instars and (iii) the pest living on the lower side of the leaflet, feeding within galleries, with limited dispersion. According to Nadarajan (1977) preference of the pest for older leaves with low potash content is a factor responsible for aggregation. In addition other abiotic factors like rainfall and pressure exerted by natural enemies may effect population density.

The 'k' value was around 2 in only four trees indicating aggregation of O. arenosella. In 13 trees it was less than two indicating highly clumped nature of O. arenosella. The remaining eight trees had the 'k' value greater than two revealing O. arenosella to approach random distribution in these trees. It can be seen from the table that wherever mean values were higher 'k' was less than two, pointing to the fact that as the mean density increase there is a tendency towards aggregation and conversely with decrease intensity the population tended to randomness. In chi square test the observed value of frequency were compared with expected value of frequencies for negative bionomial distribution. Probability of fit to the negative binomial model ranged from < 0.001 to 0.80.

b. Distribution during lean infestation period

The variance to mean ratio was greater than unity in all but two trees indicating aggregated nature of the pest. Even in the two trees it was close to one. Lloyd's index of patchiness was greater than one in all but the two cases indicating aggregation of O. arenosella. The variance to mean ratio, though above unity, seems to cluster around 1.00. The mean crowding values were only marginally more than mean, k values being fractional in all but one case indicate that their distribution tends towards logarithmic series. However, since k values varies with mean density, interpretation merely based on k values are not dependable (Southwood, 1978).

In most of the cases chi-square test has shown good agreement between expected and observed frequencies for negative binomial distribution and the probability of fit ranged between 0.02 - 0.95.

The value was less than two, revealing the cause of aggregation to be environmental namely maximum rainfall and minimum hours of sunshine. Most probably the rainfall which was maximum during this study period (470.10mm) affected the aggregation pattern.

5.3 INTER TREE SPATIAL DISTRIBUTION

a. Distribution during peak infestation period

Aggregated nature of the pest on coconut trees during peak infestation period is indicated by the variance to mean ratio being larger than unity and mean crowding being greater than mean. Lloyd's index of patchiness was greater than one, confirming the aggregation nature of the pest. The data was fitted to negative binomial distribution and the probability of fit was found to be very low (<0.001). 'k' value being fractional revealed the highly clumped nature of distribution of coconut black headed caterpillar which is approaching towards logarithmic series.

The mean clump size (λ) was less than two suggesting the environmental factors to be responsible for the aggregation. The preference of the moth to lay eggs nearer to the old infestation and the larvae to feed on older leaves with low potash content may be responsible for the aggregating nature.

b. Distribution during lean infestation period

Aggregation of the pest on coconut trees in lean infestation period was suggested by the variance to mean ratio which was greater than one and by the mean

crowding being greater than mean. It is further confirmed by the Lloy d's index of patchiness which was also larger than unity. k value (0.19) being fractional reveal that distribution is tending towards logarithmic. The mean clump size (λ) was less than two suggesting the cause of aggregation to be environmental factors.

The overall aggregation trend was similar to that of peak infestation season, with environment seeming to be dominant factor determining aggregation.

Different spatial distribution parameters like variance mean ratio, mean crowding, Lloyd's index of patchiness, k value, chi-square value and mean clump size were used by various workers to study the distribution patterns of insects. As in the case of coconut black headed caterpillar, negative bionomial distribution has been observed in Green scale of citrus (Tandon, 1985) and Thrips on Mango (Verghese et al., 1988b). Whereas random distribution of Blister Midge on Mango was noticed by Verghese et al., (1988a).

As mentioned earlier the adults preference to lay eggs near to the old infestation, aggregating tendency of early instar larvae and preferring the older leaves

with low potash content, may be the factor responsible for the contagious nature of distribution of the pest.

5.4 DISTRIBUTION OF O. arenosella IN RELATION TO DIFFERENT QUADRANTS

a. Distribution during peak population season

From the data obtained on distribution of O. arensoella in relation to different directional quadrants, it was observed that 18 out of 20 trees showed significant differences in mean O. arenosella population density. However, among the 8 sections there was no significant difference showing that height or directional quadrants had no influence on the population.

When the distribution of O. arenosella in different quadrants in 20 trees taken together was considered no significant differences in the mean O. arenosella counts in different quadrants were observed.

Except the SL quadrant, the remaining quadrants were significantly correlated with the total tree population.

b. Distribution during lean infestation period

The data on distribution of the pest in relation to different quadrants in lean infestation period revealed

that the different directions did not affect the distribution within a tree.

When the 20 trees were considered together, there was no significant difference in the mean population among different quadrants. The population counts in the quadrants NU, SU, EU, EL and WU had significant correlations with the total tree population.

Similar to the distribution of O. arenosella in this study, Tandon and Verghese (1988) observed that distribution of Idioscopus niveosparsus and Thrips palmi in mango were not significantly different in the eight different sections. All the quadrant except East Lower were signifiantly correlated with the total in case of I. niveosparsus. In thrips, only South Lower and West Lower were significantly correlated with the total. Hence, they suggested combined sampling to be restricted to these two regions. Whereas in this study, during the peak population period, no particular quadrant influenced the pest population, hence any quadrant can be selected for sampling depending upon the feasibility and time as a cost factor.

Verghese et al., (1988a) noticed no significant differences of Erosomyia indica amongst the different

sections. But infestations in East lower, South lower and South upper were significantly correlated with the total infestation. They suggested the high panicle initiation in East and South due to better sunlight availablility and probability of high infestation in this zone. In the case of O. arenosella during the lean infestation period also there was no significant difference among different quadrants. But the quadrants NU, SU, EU, WU and EL were significantly correlated to the total infestation, hence sampling has to be restricted to these quadrants during lean period of O. arenosella.

5.5 DISTRIBUTION OF O. arenosella IN RELATION TO FOUR DIRECTIONAL QUADRANTS

a. Distribution during peak infestation period

Data on distribution of O. arenosella in different directional quadrants, viz., North, South, East and West revealed that 14 out of 20 trees observed, had significant differences in mean population among directional quadrants. But no particular quadrant in the trees having significant difference in mean O. arenosella population had influence on the pest population.

No significant differences in the mean O. arenosella in different quadrants were noticed. However, all the four quadrants were highly correlated to the total tree population.

b. Distribution during lean infestation period

The data on distribution of O. arenosella in different quadrants during low infestation period revealed that 19 out of 20 coconut trees showed non-significant differences in the mean population in different quadrants.

The mean population did not show significan difference in different quadrants when the 20 trees were considered together. However, there was highly significant correlation between each quadrant counts and total tree population.

During the peak infestation and low infestation period of O. arenosella, the sampling can be done from any quadrant since no particular quadrant influences the pest population.

Tandon (1985) observed that distribution of Cocus virdis within mandarin tree was not influence

directional quadrant. It was suggested that the differences in different quadrants could be due to the initial stage of infestation which might have started from any of these directions. Also, Morris (1955), Dudley (1971) and Verghese et al., (1988b) did not observe any significant difference with different directional quadrants of the trees in case of spruce budworm, pine beetle and mango thrips, respectively. In the early part of the season, codling moth laid eggs mostly on the South-East direction on the apple trees but later this biasness disappeared (MacLellan, 1962).

5.6 DISTRIBUTION OF O. arenosella IN RELATION TO TREE HEIGHT WITHIN COCONUT TREE

To know the influence of the canopy height in the distribution of O. arenosella, the populations in the upper and lower level were estimated.

a. Distribution during peak infestation period

The data during the peak infestation period revealed in general, higher mean population per leaflet in the upper level than in the lower level. This may be due to the reason that the lowest few fronds being completely exhausted by the pest.

When the data on 20 trees were taken together, no significant differences in the mean O. arenosella population in the two levels of the tree were observed and the two levels had significant correlation with the total tree population. Hence the sampling can be done either from the upper or lower level depending upon the infestation. If the older fronds are already exhausted due to earlier infestation sampling can be done from fronds just above these.

b. Distribution during lean infestation period

The data revealed that two out of 20 trees showed significant differences in the mean O. arenosella population. However, all the trees had larger O. arenosella count in the upper level than in the lower level, since all the lower fronds were exhausted by the pest. No significant difference in the average O. arenosella counts in the two levels of the tree were observed. But the mean O. arenosella count in the two levels were significantly correlated with the total tree population. Therefore, the sampling can be done from either of the two levels, but again should be done from the fronds which are just above the completely burnt fronds.

Absence of difference in mean O. arenosella count in the two levels was noticed because a few lower fronds were completely exhausted by the pest and did not have any larvae. Also a few newly formed fronds in the centre of the crown did not have any O. arenosella.

Random distribution of Archips argyrospilus on apple tree for most of the time in a year was reported by Paradis and LeRoux (1962). They recommended sampling from one level only. Cherry and Fitzpatrick (1979) and Verghese et al., (1988b) suggested sampling of the lower canopy for citrus blackfly, Aleurocanthus woglumi and Thrips palmi, respectively. Similarly sampling of Anaphe venata from the lower canopy was suggested by Ashiru (1988) because it had the highest percentage of egg masses and larvae.

Sampling of O. arenosella can be done from any convenient level in terms of cost and mechanical difficulties as suggested for larch sawfly (Pristiphora erichsonii) (Ives, 1955), who observed variation in mean egg population in relation to tree height but, preferred sampling of mid crown only in view of the cost and mechanical difficulties of stratified sampling at different height.

5.7 DISTRIBUTION OF O. arenosella IN RELATION TO FROND POSITION ON TRUNK

When the data were subjected to analysis of variance, significant differences in mean population counts were observed in the fronds in all the five trees. Lower fronds which were completely dried were found to harbour low pest population and the upper fronds had higher population. Therefore, it is suggested that for sampling, fronds which are just above the completely dried frond must be selected. The very tender fronds in the centre of the crown region also do not harbour the pest.

Nayak (1970) and Nadarajan (1977) observed the lower fronds to be more severly attacked than the upper frond. When the infestation started the latter noticed that nutrients like sugar and proteins were more in older leaves and less of potash which seems to attract the feeding of the larvae.

No difference in mean scale populations in different mandarin leaves marked first to fifth on terminal shoots were observed by Tandon (1985). He recommends selection of any mature leaf from first to fifth, avoiding the immature leaves which harbour mostly

the crawlers and the mature old leaves; beyond the fifth leaf which have adult scales.

5.8 DISTRIBUTION OF O. arenosella POPULATION WITHIN A FROND

The data on distribution of O. arenosella in different regions of the frond, did not show significant differences in the mean O. arenosella population counts.

Hence, for sampling any infested leaflets can be randomly picked from a frond.

5.9 DISTRIBUTION OF O. arenosella WITHIN A LEAFLET

When the data on mean larval number in the base, middle and apex region of the leaflet were recorded, maximum number was observed in the middle and the least in the apex.

The variance to mean ratio was the least (0.58) in the middle region and the highest (1.00) in the base. The coefficient of variation was also the least in middle region (100.78) when the three sectors were compared which suggested that maximum population of O. arenosella is present in the middle region with minimum variability. But the correlation between the population in the basal region and that in the entire leaflet was significant ($r = 0.459$).

Tandon (1985) recommended midrib area of mandarin leaf for sampling of Coccus viridis population because of maximum scale population, low variablity, less time consumption and higher accuracy. Verghese and Rao (1985) suggested that the mid-segment contributed most to the galls on a mango leaf in case of Procontarinia matteiana. However, these two instances were for sessile insects.

In this study the middle region with higher mean density is under dispersed with least coefficient of variation but is not significantly correlated to the total population. The basal region showed significant correlation with total population but had lesser mean density than the middle. The distribution of the larvae in the leaflet varies with the stage of the larvae, they are found in groups in earlier instars and the later instars are found individually. This will alter the counts in different regions. Further, Baburaya Nayak (1970) observed the 1^{st} and 2^{nd} instar O. arenosella larvae to be present by the side of the midrib. The later instars were found webbing the margins of the leaflets and feeding inside. Since, the larvae are distributed through out the leaflet and are not very tiny and are found in few numbers when compared to other insects, the sampling of entire leaflet is suggested.

5.10 SAMPLE SIZE REQUIRED FOR ESTIMATING MEAN *O. arenosella* POPULATION

During the peak season a lower number of sample size is required to estimate *O. arenosella* population than in the lean season. It was as high as 1409 leaflets during lean season, compared to 103 leaflets in peak season. In addition, a large number of samples are required if extremely precise estimates of *O. arenosella* are desired. It was as high as 103 leaflets per tree at precision level D = 0.10 and as low as 16 leaflets per tree at precision level D = 0.25 in the peak season. Similarly, it was as high as 1409 leaflets per tree at precision level D = 0.10 and as low as 225 leaflets at precision level of D = 0.25 during the low infestation period. Thus at the low *O. arenosella* densities, precise estimates are probably not practicable. Jorge and Baranowski (1990), also felt in a similar way while studying the sample size requirement for the broad mite and citrus rust mite on limes.

Tandon (1985) recommended 60 leaves per tree for estimating mean population of *Coccus viridis* on mandarin for greater precision like life table study in natural population. A sample size of 55 panicle per tree for control and survey studies, and 92 panicles per tree for

higher precision in life table studies of Thrips palmi on mango were recommended by Verghese et al., (1988b). Based on Iwao's formula, they observed that a sample size of 125 panicles per tree was required for more reliability and can be adopted when time and man power are available becaue it is based on the distribution of insect.

5.11 APPROPRIATE TRANSFORMATION FOR STABILISING VARIANCE IN O. arenosella POPULATION

To normalize the distribution and to make the variance independent of mean, it is necessary to transform the original data before subjecting it to analysis of variance.

From the studies on distribution pattern of O. arenosella, it was observed that it followed an aggregated pattern. The mean and variance were subjected to seven transformations, viz. $\sqrt{x+1}$, log (x+1), log (x+k), log (x+k/2), log (log(x+2)), Sinh-1 $\sqrt{\frac{\beta - 1}{\alpha + 1}}\, x$ and $x^{1-b/2}$.

The original count and the transformations $\sqrt{x+1}$, log (x+1) and log (log(x+2)), when subjected to correlation analysis, showed significant positive correlation coefficients. Significant correlation

coefficents were obtained for the transformations log (x+k), log (x+k/2) and $x^{1-b/2}$. The transformation Sinh-1$\sqrt{\frac{\beta - 1}{\alpha + 1}}$ x had a non significant correlation coefficient. Therefore, it is found suitable for stabilising variance in case of O. arenosella population. This transformation makes the variance independent of mean. The transformation Sinh-1$\sqrt{\frac{\beta - 1}{\alpha + 1}}$ x was suggested by Iwao and Kuno (1971).

For negative binomial distribution, the transformations log (x+k/2) and log(x+k) were suggested by Anscombe (1948) and Kleczkowaski (1949), respectively but both the transformations were not suitable for O. arenosella population. Anderson (1965) showed that if k is in the region of 2, log (x+k/2) transformation is not appropriate. Hayman and Lowe (1961) compared four transformations and found the transformation log (x+1) to stabilize variance of cabbage aphid (B. brassicae) counts. For the biological populations, Taylor (1965) recommended the transformation $f(x) = x^{1-b/2}$.

Tandon and Veeresh (1987) tested various transformations for stabilizing variance of Coccus virdis population counts which followed negative

binomial distribution. They found only log [log(x+2)] transformation to be effective in stabilizing variance. Transformations, Sinh-1$\sqrt{\frac{\beta - 1}{\alpha + 1}}$ x, log(x+1), log(x+k), $x^{1-b/2}$ and log [log(x+k/2)] were found unsuitable. Verghese and Tandon (1988) applied various transformations for Mango hopper (Idioscopus niveosparsus) and thrips (Thrips palmi) population counts to normalise the data and observed the logarithmic transformation, especially log (x+1), to be suitable. Both the species followed a contagious distribution. But none of the transformation found suitable by the above authors, was suitable for O. arenosella count.

However, the transformation Sinh-1$\sqrt{\frac{\beta - 1}{\alpha + 1}}$ x found suitable for O. arenosella population count was reported to be sutiable for Thrips palmi count on mango by Verghese et al., (1988b). They also found the transformations log (x+k/2) and log [log(x+2)] to be suitable, which were not appropriate for O. arenosella count.

In order to apply this transformation Iwao's α and β need to be worked out. Though cumbersome, for meaningful inferences from field data of O. arenosella, entomologists have to resort to this transformation.

5.12 INTERSPECIFIC ASSOCIATIONS AMONG *Opisina arenosella*, *Apanteles taragamae* and *Parena nigrolineata*

The data on the study of associations among *O. arenosella* and two of its natural enemies, viz. *A. taragamae* and *P. nigrolineata* indicated positive associations between *O. arenosella* and *A. taragamae*, *O. arenosella* and *P. nigrolineata* and *P. nigrolineata* and *A. taragamae*.

From the mean and variance data, it was observed that the host followed an aggregation distribution and the natural enemies a random distribution. This may be due to the low population of individual natural enemies.

The 2 x 2 analysis showed that a positive association existed between *O. arenosella* and *A. taragamae* due to specificity in parasitization by the later. There was a certain degree of overlapping between the two species as observed by r index value. A value of 1.00 indicates complete overlapping, while zero indicates complete exclusion. Although in the present case the association was positive, it was not very strong.

The carabid predator, P. nigrolineata showed a positive association with the host which was not significant (r = 0.13) thus indicating only a partial overlap of the two species.

No association was observed between A. taragamae and P. nigrolineata. The value of degree of overlapping (r = 0.05) indicated independent nature of dispersion of the two species. However, the predators did not discriminate between parasitized and nonparasitized host larvae.

The interspecific association studies showed that the parasite with a slightly higher density than the predator had significant association with the host, but with a tendency towards independent occurrence and only partial overlap.

Smith (1980) suggested that interspecific association may result from species interaction, food chain co-action or similarity in adaptation and response to the environment. The interspecific associations existed between the three species because they occupied the same habitat, i.e. the lower side of the coconut leaflets. Also, A. taragamae and P. nigrolineata are the parasite and predator, respectively of O. arenosella. Cole (1949), suggested that a positive association

occurs when two species exhibit overlapping "habitat" requirements.

Joseph and Sterling (1983) studied the interspecific association between the red imported fire ant, Solenopsis invicta and several insect inhabitants of east Texas cotton fields and found a positive association between them. They suggest the possible reasons for the positive associations as; (1) both insect species select the same habitat or resources; (2) one or both insect species are in same way attracted to each other; (3) both insect species interact in a way that is beneficial or harmful to one or both of the species (i.e., mutualism, predation, parasitism); (4) the ants may feed on fecal matter, excreta, or exuvia of other insects.

In a guava ecosystem a positive association of Menochilus sexmaculatus and Camponotus compressus with Aphis gossypii and a negative association between M. sexmaculatus and C. compressus was recorded by Verghese and Tandon (1987). This study further showed that 2 x 2 analysis only qualified the association but more meaningful inferences of applied value require statistical tools to quantify the association in terms of niche overlap and spatial correlation, Iwao (1979).

SUMMARY

SUMMARY

The black headed caterpillar O. arenosella is a long standing pest problem of the coconut and there is no information regarding its population ecology which includes phenology, inter and intra-tree spatial distribution and factor affecting its, interactions with its natural enemies and sampling plan. To develop an Integrated Pest Management programme based on sound ecological principles, it is most essential to generate information on these aspects. Hence the present investigations on population ecology of coconut black headed caterpillar were carried out and the results are summarised below.

* Although the population of O. arenosella is present throughout the year in coconut gardens, it attains peak during March to May and becomes low during September to December. Under Bangalore conditions the major factors regulating the pest population were mean maximum temperature, sunshine and rainfall. The three species of natural enemies recorded in the present case viz., Goniozus nephantidis, Apanteles taragamae and Parena nigrolineata did not play a significant role in regulating the pest population.

* Intra-tree spatial distribution studied through various indicies of dispersion namely, variance mean ratio, mean crowding, Lloyd index of patchiness, k value and finally fitted to negative binomial distribution revealed that during peak population period, the larvae followed contagious distribution which was very close to negative binomial model and probability of fit ranged between < 0.001 to 0.80. Similar trend was observed during lean period. However the probability of fit was a little higher in the range of 0.02 to 0.95.

* The inter-tree spatial distribution studied through above mentioned statistical parameters confirmed the aggregating distribution of this pest. However when the data was fitted to negative binomial distribution, the probability of fit was found to be very low (< 0.001). The fractional values of dispersion index k revealed that the distribution is tending towards logarithmic series.

* The aggregation of inter-tree spatial distribution was explained by mean clump size (λ). During both the periods the value was less than two which explained the cause of aggregation as environmental

heterogeneity. The environmental heterogeneity refer here to tree to tree variability in terms of availability of oviposition site and heavy rainfalll which indirectly affect the oviposition. Further in intra-tree distribution during lean period the mean clump size was less than two in all the cases. However during peak season the value of aggregation index in most of the cases was around two and more than two, which revealed that during peak season period the pest population was high. It is both the environmental factors and behavioural factors which are causing aggregation. During peak season initial infestation on the frond attract further moths to lay eggs near the old infestation.

* Studies conducted on dispersion of O. arenosella larvae within the tree in different eight sectors, four cardinal directions (N, S, E and W) and two canopy heights (upper and lower) revealed that mean population did not differ significantly in these sectors.

* The population distribution in different fronds marked from the base showed significant difference between 1st, 5th and 10th, 15th frond. Low

population was observed in the 1st and 5th frond in comparison to 10th and 15th. However, this was due to the fact that these lower fronds were exhausted by the larvae. Further distribution within the frond (base, middle and apex) did not have significant difference in the larval distribution. Similar observations were made in the distribution within the leaflet.

* To estimate O. arenosella population a large number of sample is required in lean season (225 at D = 0.25) than in peak season (16 at D = 0.25). The sampling unit will be the whole leaflet.

* To normalize the distribution and to make the variance independent of mean, the transformation $\sinh^{-1}\sqrt{\frac{\beta - 1}{\alpha + 1}}\, x$ is found suitable for O. arenosella population.

* A weak positive association exists between the pest O. arenosella and its parasitoid A. taragamae and also with its predator P. nigrolineata, which is revealed by the degree of overlapping. However P. nigrolineata and A. taragamae were independent of each other.

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* Original not seen